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THE ROTPROOFING EFFICACY OF MIXTURES OF METALLIC NAPHTHENATES[1]

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Abstract

The weathering characteristics of cotton duck treated with copper or zinc naphthenate containing mercury naphthenate or phenyl mercury naphthenate, and the effect of weathering on the rotproofing efficacy of these treatments as judged by the soil burial method, have been investigated. The presence of the mercury compounds reduced the loss of copper during burial and did not affect the weathering properties of the treated fabrics.

In an investigation of the rotproofing efficacy of binary mixtures, the naphthenates of cadmium, chromium, copper, iron, lead, mercury, silver, and zinc, containing a total of 0.2% metal, showed in general greater resistance to attack during soil burial than did samples containing the same percentage of metal in the form of single naphthenates. Ternary mixtures of the naphthenates of cadmium, copper, lead, mercury, silver, and zinc, applied to cotton fabric in equivalent concentration of total metal, were in general more effective than the binary mixtures of the same compounds.

Metallic naphthenates which have been used for the rotproofing of cellulosic textiles, cordage, etc., include chiefly those of copper and zinc. It has been found (6)* that the naphthenic acids used in the preparation of naphthenates impart considerable rot resistance to cotton fabrics. There is little doubt that this property of naphthenic acids contributes markedly to the usefulness as a rotproofer of such compounds as copper naphthenate in which the cation is itself a powerful fungicide. The amount of published information on other metallic naphthenates is limited and does not indicate any high degree of efficacy when these compounds are used singly.

Cadmium naphthenate has been reported (8) to be less effective than copper naphthenate. A commercial preparation containing iron naphthenate in conjunction with an aluminium compound and tar oils gave some protection when used on cotton fish nets, but was inferior to copper or zinc naphthenates (1). In tests with jute (4) mercury naphthenate was found to be inferior to copper naphthenate. Cotton duck treated with silver naphthenate in concentrations of 0.0084 and 0.0421% silver in Stoddard solvent solutions gave severe losses in breaking strength in a four weeks' soil burial test (7). Although these concentrations were of a very low order, it has been claimed (8) that

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silver compounds have no practical value as fungus inhibitors on fabric or cordage and that their efficiency is not sufficient to offset their cost. However, in another investigation (5) silver naphthenate in conjunction with chlorinated rubber and a plasticizer gave promising results on linen twine subjected to sea immersion.

In a previous publication (2) it had been shown that the addition of small quantities of mercury naphthenate to copper naphthenate improved greatly the efficacy of the latter compound in inhibiting the growth on unbleached cotton duck of the surface growing fungus *Aspergillus niger* and a cellulose destroying species of *Penicillium*. The data given in this paper comprise the results of two further studies. The first of these covers an extension of the previous work to a study of the comparative rotproofing efficacy, as judged by soil burial and resistance to weathering, of phenyl mercury naphthenate and mercury naphthenate in admixture with copper and zinc naphthenates, respectively. Secondly, the rotproofing efficacy as measured by the soil burial test was determined for other metallic naphthenates, viz., those of cadmium, chromium, copper, iron, lead, mercury, silver, and zinc, in binary mixtures containing equal concentrations of the metals, and, with the exception of chromium and iron, in ternary mixtures containing equal concentrations of metals. The single naphthenates were included as controls.

A. Materials and Methods

The metallic naphthenates used were prepared by Nuodex Products Inc., Elizabeth, N.J., U.S.A., or by Nuodex Products of Canada Ltd., Leaside (Toronto), Ont., and were obtained through the latter firm. They contained the percentages of metal shown, viz.: cadmium 8.10, chromium 7.95, copper 8.10, iron 6.06, lead 23.93, mercury 24.90, phenyl mercury 10.08, silver 8.20, and zinc 8.18.

The fabrics used were unbleached cotton army ducks weighing 10 and 12 oz. per sq. yd., and a No. 8 unbleached duck of 18 oz. per sq. yd. Throughout this paper these ducks are referred to as '10 oz.', '12 oz.', and '18 oz.' ducks, respectively.

The treatments were applied from solutions in Stoddard solvent as previously described (2). In the treatments involving zinc naphthenate mixed with mercury naphthenate and phenyl mercury naphthenate respectively, a wax waterproofing compound consisting of a mixture of paraffin wax and petrolatum (3) was incorporated in the treating solution to give approximately 10% of the mixture on the dry weight of the treated fabric.

In the study of the effect of weathering and of soil burial on copper and zinc naphthenates in the presence of mercury compounds the percentage of copper in the copper naphthenate treated samples was 0.20, the mercury compounds being present in amounts corresponding to 0.005, 0.01, 0.03, and 0.05% mercury; the percentage of zinc in the samples treated with zinc naphthenate was 0.79, the mercury compounds being present in amounts

corresponding to 0.01 and 0.05% mercury. All percentages of metal are calculated on the basis of the dry treated sample, the copper and zinc being determined as described previously (9, 10).

The samples used in studying the effect of binary mixtures of metallic naphthenates contained approximately 0.1% of each metal in the form of naphthenates, the control samples (one metal only) containing 0.1 and 0.2% metal. With the samples containing ternary mixtures of naphthenates the total content of metal was 0.2% as above, the content of each metal being approximately 0.07%, the control samples being as described above. The percentages of metal shown were calculated on the dry weight of the treated fabric and were obtained from the wet pick-up data.

The details of the leaching, soil burial, weathering, and breaking strength techniques employed, and also the record of weather conditions during the exposure period, have been given in an earlier paper (3). In certain cases an estimate of microbiological attack occurring during soil burial was made on the basis of an arbitrary system of growth ratings (*A* to *F*) obtained independently by three observers. It was found that the observations so obtained were sufficiently uniform to permit this system of rating to be used in judging the extent of microbiological attack without the necessity of carrying out breaking strength measurements. The ratings used were as follows:

A—No growth.

B—Very slight surface growth.

C—Moderate growth but not over whole surface; fabric remains strong to pulling by hand.

D—Heavy growth over whole surface; noticeable weakening of fabric.

E—Very heavy growth over whole surface with noticeable thinning of fabric and possible development of holes.

F—Fabric partially or entirely disintegrated.

B. Experimental Results

1. *Effect of Mercury Compounds on the Soil Burial and Weathering Characteristics of Copper and Zinc Naphthenate Treated Samples*

Table I gives the data showing the effect of soil burial on loss in breaking strength and copper content of 18 oz. cotton duck treated with mixtures of copper naphthenate and mercury naphthenate, or phenyl mercury naphthenate. The effect of soil burial, weathering, and weathering followed by soil burial, on loss in breaking strength of 12 oz. cotton duck similarly treated is shown in Table II. Table III gives similar data for 10 oz. duck treated with zinc naphthenate and the two above-mentioned mercury compounds.

(*a*) *Burial Effects*

It will be apparent from the data in Table I that the samples of duck treated with the mercury compounds alone showed little or no resistance to rotting. The sample treated with copper naphthenate alone (0.20% copper) showed a

TABLE I

EFFECT OF BURIAL ON THE BREAKING STRENGTH AND COPPER CONTENT OF 18 OZ. COTTON DUCK TREATED WITH COPPER NAPHTHENATE PLUS MERCURY NAPHTHENATE OR PHENYL MERCURY NAPHTHENATE

Original metal concentration, %		Decrease in breaking strength, % of orig.				Decrease in copper content, % of orig.			
		Mercury naphthenate		Phenyl mercury naphthenate		Mercury naphthenate		Phenyl mercury naphthenate	
Copper	Mercury	Leached 24 hr. and buried		Leached 24 hr. and buried		Leached 24 hr. and buried		Leached 24 hr. and buried	
		2 wk.	4 wk.	2 wk.	4 wk.	2 wk.	4 wk.	2 wk.	4 wk.
0.20	0.005	6	38	7	32	25	20	20	23
0.20	0.01	0	28	8	10	—	15	23	23
0.20	0.03	5	5	+2	5	30	20	20	20
0.20	0.05	0	8	12	4	—	15	20	20
Controls									
0	0.005	78	—	71	—	—	—	—	—
0	0.01	88	—	78	—	—	—	—	—
0	0.03	92	—	87	—	—	—	—	—
0	0.05	84	—	83	—	—	—	—	—
0.20	0	30	64	—	—	50	64	—	—

TABLE II

EFFECT OF OUTDOOR WEATHERING AND BURIAL ON THE BREAKING STRENGTH OF 12 OZ. COTTON DUCK TREATED WITH COPPER NAPHTHENATE PLUS MERCURY NAPHTHENATE OR PHENYL MERCURY NAPHTHENATE

Original metal concentration, %		Decrease in breaking strength, % of original									
		Mercury naphthenate					Phenyl mercury napthenate				
		Weath. 4 mo.	Weathered 4 mo. and buried		Buried 4 wk.	Leached 24 hr. and buried 4 wk.	Weath. 4 mo.	Weathered 4 mo. and buried		Buried 4 wk.	Leached 24 hr. and buried 4 wk.
Copper	Mercury		2 wk.	4 wk.				2 wk.	4 wk.		
0.26	0.005	36	50	97	27	37	31	57	—	15	10
0.26	0.01	37	65	96	28	31	36	49	—	14	17
0.26	0.03	35	54	96	17	31	32	55	—	16	31
0.26	0.05	39	64	95	5	16	34	49	—	—	8
Controls											
0	0.005	34	93	93	—	—	39	75	—	—	—
0	0.01	32	90	97	—	—	40	76	—	—	—
0	0.03	39	87	97	—	—	40	—	—	—	—
0	0.05	29	83	93	—	—	41	—	—	—	—
0.26	0	36	54	96	35	76	—	—	—	—	—
0	0	42	—	—	—	—	—	—	—	—	—

TABLE III

EFFECT OF OUTDOOR WEATHERING AND BURIAL ON THE BREAKING STRENGTH OF 10 OZ. COTTON DUCK TREATED WITH ZINC NAPHTHENATE PLUS MERCURY NAPHTHENATE OR PHENYL MERCURY NAPHTHENATE AND WAX

Original metal concentration, %		Decrease in breaking strength, % of original											
		Mercury naphthenate						Phenyl mercury naphthenate					
Zinc	Mercury	Weath. 4 mo.	Weath. 4 mo. and buried		Buried 2 wk.	Leached 24 hr. and buried		Weath. 4 mo.	Weath. 4 mo. and buried		Buried 2 wk.	Leached 24 hr. and buried	
			2 wk.	4 wk.		2 wk.	4 wk.		2 wk.	4 wk.		2 wk.	4 wk.
Without wax													
0.79	0.01	43	79	97	9	1	83	44	84	98	+16	+1	97
0.79	0.05	47	85	97	+7	6	86	46	90	97	14	+7	96
Controls													
0	0.05	47	81	—	100	100	—	—	—	—	—	—	—
0.79	0	38	81	96	20	27	93	—	—	—	—	—	—
0	0	41	89	—	98	100	—	—	—	—	—	—	—
With wax													
0.79	0.01	66	82	97	1	+6	74	68	77	98	+6	+8	74
0.79	0.05	67	81	97	7	+1	38	63	72	98	9	7	41
Controls													
0.79	0	68	82	97	8	17	82	—	—	—	—	—	—
0	0	69	87	—	100	100	—	—	—	—	—	—	—

breaking strength loss of 30 and 64% after leaching followed by two and four weeks' burial, respectively. The addition of the mercury compounds reduced these losses to an insignificantly low level. Similar breaking strength effects were observed with the 12 oz. duck (Table II), the best resistance to soil burial being shown by the copper treated sample containing 0.05% mercury. The presence of the mercury compounds likewise reduced the strength losses resulting from soil burial in the samples treated with zinc naphthenate (Table III).

It is of interest to note that the loss of copper during soil burial (Table I) was considerably less in the presence of the mercury compounds. This is probably due to the effect of the latter compounds in reducing the activity of copper tolerant organisms, many of which are known to bring about solubilization and consequent loss by leaching of copper compounds.

(*b*) *Weathering Effects*

It will be noted that with the samples treated with copper and mercury naphthenates either singly or in mixtures (Table II), or with zinc and mercury naphthenates (Table III), there was no evidence of increased breaking strength losses over that shown by the untreated control on weathering.

In this series the increased breaking strength losses shown by the waxed samples substantiate previous data covering the use of the same wax compound (3). Further investigation has shown that this effect is due largely or entirely to the petrolatum constituent. The mercury compounds had no effect on the breaking strength losses of copper naphthenate or zinc naphthenate treated samples followed by soil burial. It has previously been shown (3) that mercury naphthenate and zinc naphthenate are readily removed by weathering for four months, and this explains the lack of efficiency with respect to rotproofing after weathering.

2. *Effect of Soil Burial on Samples Treated with Binary and Ternary Mixtures of Metallic Naphthenates*

Tables IV, VI, VIII, and X give growth rating data for binary and ternary mixtures of the various metallic naphthenates after leaching followed by burial for two and four weeks, respectively. The data given in Tables V, VII, IX, and XI show the frequency of occurrence of growth ratings for various metallic radicles when used as single naphthenates or binary mixtures of naphthenates (Tables V and VII) or ternary mixtures of naphthenates (Tables IX and XI).

TABLE IV

GROWTH RATING OF 10 OZ. COTTON DUCK TREATED WITH METALLIC NAPHTHENATES, SINGLY (0.1 and 0.2% METAL ON FABRIC) AND IN BINARY MIXTURES (0.1% OF EACH METAL ON FABRIC) AFTER BURIAL FOR TWO WEEKS WITH PRELIMINARY LEACHING

Metallic naphthenate (0.1% metal)	Metallic naphthenate (0.1% metal) in combination with metallic naphthenate (0.1% metal) in left-hand column							
	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Silver	Zinc
—	*D*	*D*	*C-D*	*D-E*	*E*	*D*	*D*	*D*
Cadmium	**C**	*D*	*B*	*D*	*C*	*A*	*C*	*C*
Chromium	*D*	**D**	*D*	*E*	*E*	*B*	*E*	*D*
Copper	*B*	*D*	**B**	*D*	*D*	*A*	*B*	*C*
Iron	*D*	*E*	*D*	**E**	*D*	*B*	*D*	*D*
Lead	*C*	*E*	*D*	*D*	**D**	*B*	*D*	*C*
Mercury	*A*	*B*	*A*	*B*	*B*	**B**	*B*	*B*
Silver	*C*	*E*	*B*	*D*	*D*	*B*	**D**	C
Zinc	*C*	*D*	*C*	*D*	*C*	*B*	*C*	**D**

The growth ratings for samples treated with single naphthenates and with binary mixtures of naphthenates and subjected to soil burial for two weeks with preliminary leaching (Table IV) show that copper and mercury when used singly (0.2% metal) gave marked resistance to microbiological attack; cadmium gave moderate resistance, whereas the other compounds gave little

TABLE V

FREQUENCY OF OCCURRENCE OF GROWTH RATINGS FOR VARIOUS METALLIC RADICLES WHEN USED AS SINGLE NAPHTHENATES (0.2% METAL ON FABRIC) OR IN BINARY MIXTURES OF NAPHTHENATES (0.1% OF EACH METAL ON FABRIC), AFTER BURIAL FOR TWO WEEKS WITH PRELIMINARY LEACHING

Metallic radicle	*A*		*B*		*C*		*D*		*E*		*F*	
	1[1]	2[2]	1	2	1	2	1	2	1	2	1	2
Cadmium	—	1	—	1	1	3	—	2	—	—	—	—
Chromium	—	—	—	1	—	—	1	3	—	3	—	—
Copper	—	1	1	2	—	1	—	3	—	—	—	—
Iron	—	—	—	1	—	—	—	5	1	1	—	—
Lead	—	—	—	1	—	2	1	3	—	1	—	—
Mercury	—	2	1	5	—	—	—	—	—	—	—	—
Silver	—	—	—	2	—	2	1	2	—	1	—	—
Zinc	—	—	—	1	—	4	1	2	—	—	—	—
Total occurrence	0	4	2	14	1	12	4	20	1	6	0	0
% of possible occurrence	0	7	25	25	13	21	50	36	13	11	0	0

[1] *Single compound.*
[2] *Binary mixture of compounds.*

TABLE VI

GROWTH RATING OF 10 OZ. COTTON DUCK TREATED WITH METALLIC NAPHTHENATES, SINGLY (0.1 AND 0.2% METAL ON FABRIC) AND IN BINARY MIXTURES (0.1% OF EACH METAL ON FABRIC) AFTER BURIAL FOR FOUR WEEKS WITH PRELIMINARY LEACHING

Metallic naphthenate (0.1% metal)	Metallic naphthenate (0.1% metal) in combination with metallic naphthenate (0.1% metal) in left-hand column							
	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Silver	Zinc
—	*E*	*F*	*E*	*F*	*F*	*F*	*F*	*F*
Cadmium	**D**	*E*	*D*	*E*	*E*	*D*	*C*	*E*
Chromium	*E*	**F**	*E*	*F*	*F*	*E*	*E*	*F*
Copper	*D*	*E*	**D**	*E*	*E*	*B*	*C*	*E*
Iron	*E*	*F*	*E*	**F**	*F*	*F*	*E*	*F*
Lead	*E*	*F*	*E*	*F*	**F**	*F*	*F*	*F*
Mercury	*D*	*E*	*B*	*F*	*F*	**E**	*E*	*E*
Silver	*C*	*E*	*C*	*E*	*F*	*E*	**F**	*C*
Zinc	*E*	*F*	*E*	*F*	*F*	*E*	*C*	**E**

or no resistance. A comparison of the over-all effectiveness of the compounds is given in Table V, in which the frequency of occurrence of the six growth ratings are shown for the single and binary mixture treatments. It will be noted that, based on the percentage of possible occurrence, 25% of the single compounds and 32% of the binary mixtures gave growth ratings of *A* or *B*. Including the ratings for moderate growth (rating *C*) which embraces those

TABLE VII

FREQUENCY OF OCCURRENCE OF GROWTH RATINGS FOR VARIOUS METALLIC RADICLES WHEN USED AS SINGLE NAPHTHENATES (0.2% METAL ON FABRIC) OR IN BINARY MIXTURES OF NAPHTHENATES (0.1% OF EACH METAL ON FABRIC), AFTER BURIAL FOR FOUR WEEKS WITH PRELIMINARY LEACHING

Metallic radicle	*A*		*B*		*C*		*D*		*E*		*F*	
	1[1]	2[2]	1	2	1	2	1	2	1	2	1	2
Cadmium	—	—	—	—	—	1	1	2	—	4	—	—
Chromium	—	—	—	—	—	—	—	—	—	4	1	3
Copper	—	—	—	1	—	1	1	2	—	3	—	—
Iron	—	—	—	—	—	—	—	—	—	3	1	4
Lead	—	—	—	—	—	—	—	—	—	2	1	5
Mercury	—	—	—	1	—	—	—	1	1	3	—	2
Silver	—	—	—	—	—	3	—	—	—	3	1	2
Zinc	—	—	—	—	—	1	—	1	1	2	—	3
Total occurrence	0	0	0	2	0	6	2	6	2	24	4	18
% of possible occurrence	0	0	0	4	0	11	25	11	25	43	50	32

[1] *Single compound.*
[2] *Binary mixture of compounds.*

TABLE VIII

GROWTH RATING OF 10 OZ. COTTON DUCK TREATED WITH METALLIC NAPHTHENATES, SINGLY (0.2% METAL ON FABRIC) AND IN TERNARY MIXTURES (0.07% OF EACH METAL ON FABRIC) AFTER BURIAL FOR TWO WEEKS WITH PRELIMINARY LEACHING

Metallic naphthenate	Metallic naphthenates in mixture with metallic naphthenate in left-hand column (total concentration on fabric = 0.2% metal)																				
	Cadmium plus						Copper plus					Lead plus				Mercury plus			Silver plus		Zinc plus
	Cd	Cu	Pb	Hg	Ag	Zn	Cu	Pb	Hg	Ag	Zn	Pb	Hg	Ag	Zn	Hg	Ag	Zn	Ag	Zn	Zn
Cadmium	**D**	—	—	—	—	—	—	*C*	*A*	*C*	*B*	—	*A*	*C*	*D*	—	*A*	*C*	—	*C*	—
Copper	—	—	*C*	*A*	*C*	*B*	**C**	—	—	—	—	—	*B*	*C*	*D*	—	*B*	*A*	—	*C*	—
Lead	—	*C*	—	*A*	*C*	*D*	—	—	*B*	*C*	*D*	**D**	—	—	—	—	*C*	*B*	—	*C*	—
Mercury	—	*A*	*A*	—	*A*	*C*	—	*B*	—	*B*	*A*	—	—	*C*	*B*	**C**	—	—	—	*B*	—
Silver	—	*C*	*C*	*A*	—	*C*	—	*C*	*B*	—	*C*	—	*C*	—	*C*	—	—	*B*	**D**	—	—
Zinc	—	*B*	*D*	*C*	*C*	—	—	*D*	*A*	*C*	—	—	*B*	*C*	—	—	*B*	—	—	—	**D**

samples that did not show significant loss of strength, the percentages are 38 and 53 for the single compounds and the binary mixtures, respectively.

Considering the various metals it will be noted that mercury gave the best over-all performance, showing no growth when mixed with cadmium or copper and only slight surface growth in admixture with the other metals. The order of decreasing efficiencies for the other metals in binary mixtures was: copper, cadmium, silver, zinc, lead, chromium, and iron.

The data for the four week burial of the same samples (Table VI) show that in all cases the samples treated with the single compounds gave growth ratings

TABLE IX

FREQUENCY OF OCCURRENCE OF GROWTH RATINGS FOR VARIOUS METALLIC RADICLES WHEN USED AS SINGLE NAPHTHENATES (0.2% METAL ON FABRIC) OR IN TERNARY MIXTURES OF NAPHTHENATES (0.07% OF EACH METAL ON FABRIC) AFTER BURIAL FOR TWO WEEKS WITH PRELIMINARY LEACHING

Metallic radicle	*A*		*B*		*C*		*D*		*E*		*F*	
	1[1]	3[2]	1	3	1	3	1	3	1	3	1	3
Cadmium	—	3	—	1	1	5	1	1	—	—	—	—
Copper	—	2	—	3	—	4	—	1	—	—	—	—
Lead	—	1	—	2	1	5	—	2	—	—	—	—
Mercury	—	4	—	4	1	2	—	—	—	—	—	—
Silver	—	1	—	2	—	7	1	—	—	—	—	—
Zinc	—	1	—	3	—	4	1	2	—	—	—	—
Total occurrence	0	12	0	15	3	27	3	6	0	0	0	0
% of possible occurrence	0	20	0	25	50	45	50	10	0	0	0	0

[1] *Single compound.*

[2] *Ternary mixture of compounds.*

TABLE X

GROWTH RATING OF 10 OZ. COTTON DUCK TREATED WITH METALLIC NAPHTHENATES, SINGLY (0.2% METAL ON FABRIC), IN BINARY MIXTURES (0.1% OF EACH METAL ON FABRIC) AND TERNARY MIXTURES (0.07% OF EACH METAL ON FABRIC) AFTER BURIAL FOR FOUR WEEKS WITH PRELIMINARY LEACHING

Metallic naphthenate	Metallic naphthenates in mixture with metallic naphthenate in left-hand column (total concentration on fabric = 0.2% metal)																				
	Cadmium plus						Copper plus					Lead plus				Mercury plus			Silver plus		Zinc plus
	Cd	Cu	Pb	Hg	Ag	Zn	Cu	Pb	Hg	Ag	Zn	Pb	Hg	Ag	Zn	Hg	Ag	Zn	Ag	Zn	Zn
—	**E**	*D*	*E*	*F*	*E*	*F*	**D**	*E*	*D*	*C*	*E*	**F**	*F*	*F*	*F*	**F**	*F*	*F*	**F**	*F*	**E**
Cadmium	**E**	—	—	—	—	—	—	*E*	*D*	*E*	*D*	—	*F*	*E*	*E*	—	*B*	*F*	—	*D*	—
Copper	—	—	*E*	*D*	*E*	*D*	**D**	—	—	—	—	—	*F*	*D*	*E*	—	*C*	*E*	—	*D*	—
Lead	—	*E*	—	*F*	*E*	*E*	—	—	*F*	*D*	*F*	**F**	—	—	—	—	*F*	*F*	—	*F*	—
Mercury	—	*D*	*F*	—	*B*	*F*	—	*F*	—	*C*	*E*	—	—	*F*	*F*	**F**	—	—	—	*F*	—
Silver	—	*E*	*E*	*B*	—	*D*	—	*D*	*C*	—	*D*	—	*F*	—	*F*	—	—	*F*	**F**	—	—
Zinc	—	*D*	*E*	*F*	*D*	—	—	*F*	*E*	*D*	—	—	*F*	*F*	—	—	—	—	—	—	**E**

of *D* or poorer, although it was noted that with the cadmium and with the copper treated samples the growth while heavy was not as intense as with the other compounds. The most effective treatment was the mercury–copper mixture, while mixtures of silver with copper and with cadmium or zinc were moderately effective. From the data for frequency of occurrence of the various ratings (Table VII), it will be noted that approximately 15% of the binary mixtures showed ratings of *C* or better, whereas none of the single compounds showed ratings better than *D*.

TABLE XI

FREQUENCY OF OCCURRENCE OF GROWTH RATINGS FOR VARIOUS METALLIC RADICLES WHEN USED AS SINGLE NAPHTHENATES (0.2% METAL ON FABRIC), IN BINARY MIXTURES (0.1% OF EACH METAL ON FABRIC), AND TERNARY MIXTURES (0.07% OF EACH METAL ON FABRIC) AFTER BURIAL FOR FOUR WEEKS WITH PRELIMINARY LEACHING

Metallic radicle	*A*			*B*			*C*			*D*			*E*			*F*		
	1[1]	2[2]	3[3]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cadmium	—	—	—	—	—	1	—	—	—	—	1	3	1	2	4	—	2	2
Copper	—	—	—	—	—	—	—	1	1	1	3	4	—	1	3	—	—	2
Lead	—	—	—	—	—	—	—	—	—	—	1	1	—	1	3	1	3	6
Mercury	—	—	—	—	—	1	—	—	1	—	1	1	—	—	1	1	4	6
Silver	—	—	—	—	—	1	—	1	1	—	—	3	—	1	2	1	3	3
Zinc	—	—	—	—	—	—	—	—	—	—	—	3	1	1	2	—	4	5
Total occurrence	0	0	0	0	0	3	0	2	3	1	6	15	2	6	15	3	16	24
% of possible occurrence	0	0	0	0	0	5	0	7	5	17	20	25	33	20	25	50	53	40

[1] *Single compound.*
[2] *Binary mixture of compounds.*
[3] *Ternary mixture of compounds.*

Owing to the relatively poor performance of the chromium and iron compounds in the above investigation they were omitted from the subsequent study dealing with ternary mixtures. In this study, control tests using fabric treated with single compounds subjected to a two week burial period, and also binary mixtures subjected to a four week burial period, were run simultaneously to provide a basis of comparison with the first series. The data obtained with these controls suggest that the soil used in the second series was somewhat more active than that used in the first series. The data indicate that for a two week burial period (Tables VIII and IX), the ternary mixtures were considerably more effective than the single compounds. It will be noted that the percentage of possible occurrence of growth ratings of *C* or better was 90% for the ternary mixtures, compared with 50% for the single compounds. Ternary mixtures on fabrics that showed no growth were: mercury–cadmium–copper, mercury–cadmium–lead, mercury–cadmium–silver, and mercury–copper–zinc. Very slight growth was shown by fabric treated with copper–cadmium–zinc, mercury–copper–silver, mercury–lead–zinc, and mercury–silver–zinc. The data for the fabric containing ternary mixtures and subjected to a four week burial period (Tables X and XI) indicate that these mixtures were on the whole more effective than the binary mixtures, and these in turn were more effective than the single compounds. The only treatment showing a *B* rating was the mercury–cadmium–silver mixture. All other treatments gave ratings of *C* or less.

The effectiveness of certain of the binary and ternary mixtures compared with the corresponding single compounds is illustrated in Figs. 1 to 9.

C. Colour of Treated Fabrics

Since the colour imparted to fabrics by rotproofing treatments is of interest to the textile trade, the following data on the colours of the treated fabrics used in this investigation are given. For the single treatments in concentration of 0.2% metal, the colours of the treated samples were as follows: copper—medium blue green; silver—rose purple; chromium—bluish grey; iron—cream; cadmium, lead, mercury, and zinc—colourless.

All binary mixtures containing silver ranged in shade from light rose to mauve. Those containing copper were pale bluish green, with the exception of copper plus silver, which was mauve. All other mixtures were either light grey, cream, or colourless.

Ternary mixtures were pale green in the presence of copper, all others being either very pale rose or colourless.

It would be expected that in higher concentrations there would be a deepening in the shade of the coloured samples.

It is of interest to note that certain binary or ternary mixtures (e.g., cadmium–mercury, cadmium–mercury–lead, and cadmium–mercury–silver) provided treatments that were nearly colourless and that had rotproofing efficacies superior to that of copper naphthenate used singly.

Acknowledgments

The authors wish to acknowledge with thanks the kindness of Nuodex Products Inc., Elizabeth, N.J., U.S.A., and Nuodex Products of Canada Ltd., Leaside (Toronto), Ont., for providing supplies of the naphthenates used in this investigation; also to Miss E. E. Raphael and Messrs. H. S. Quinn and B. H. Pout for assistance in carrying out the work.

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(Figs. 1 to 9 follow.)

PLATE I

FIGS. 1-5. *Binary mixtures of naphthenates on 10 oz. cotton duck, leached 24 hr., buried for two and four weeks.*

FIG. 1. *Silver and zinc—(buried two weeks)*
Left —Silver (0.1%) + zinc (0.1%)
Centre—Silver (0.2%)
Right —Zinc (0.2%)

FIG. 2. *Silver and zinc—(buried four weeks)*
Left —Silver (0.1%) + zinc (0.1%)
Centre—Silver (0.2%)
Right —Zinc (0.2%)

FIG. 3. *Copper and mercury—(buried four weeks)*
Left —Copper (0.1%) + mercury (0.1%)
Centre—Copper (0.2%)
Right —Mercury (0.2%)

FIG. 4. *Copper and silver—(buried four weeks)*
Left —Copper (0.1%) + silver (0.1%)
Centre—Copper (0.2%)
Right —Silver (0.2%)

FIG. 5. *Cadmium and silver—(buried four weeks)*
Left —Cadmium (0.1%) + silver (0.1%)
Centre—Cadmium (0.2%)
Right —Silver (0.2%)

PLATE II

FIGS. 6 and 7. *Ternary mixtures of naphthenates on 10 oz. cotton duck, leached 24 hr. and buried two weeks.*

FIG. 6. *Copper, cadmium, and zinc—*
From left to right
Copper (0.07%) + cadmium (0.07%) + zinc (0.07%);
Copper (0.2%); cadmium (0.2%); zinc (0.2%).

FIG. 7. *Mercury, lead, and zinc—*
From left to right
Mercury (0.07%) + lead (0.07%) + zinc (0.07%);
Mercury (0.2%); lead (0.2%); zinc (0.2%).

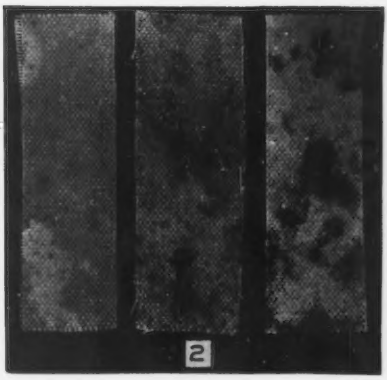
PLATE III

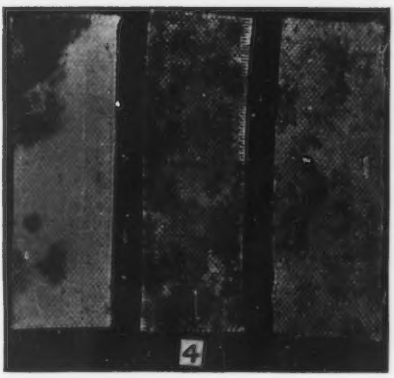
FIGS. 8 and 9. *Ternary mixtures of naphthenates on 10 oz. cotton duck, leached 24 hr. and buried two weeks.*

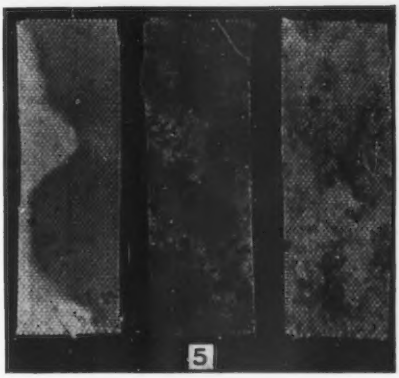
FIG. 8. *Mercury, silver, and zinc—*
From left to right
Mercury (0.07%) + silver (0.07%) + zinc (0.07%);
Mercury (0.2%); silver (0.2%); zinc (0.2%).

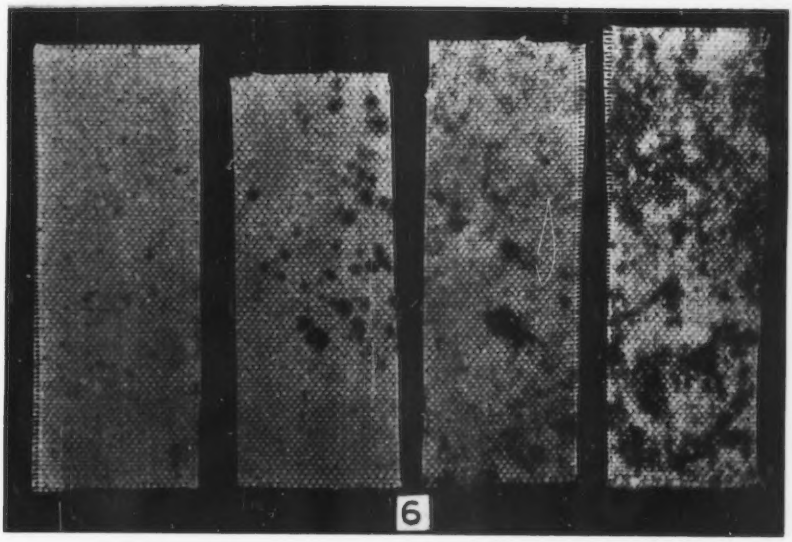
FIG. 9. *Cadmium, mercury, and silver—*
From left to right
Cadmium (0.07%) + mercury (0.07%) + silver (0.07%);
Cadmium (0.2%); mercury (0.2%); silver (0.2%).

PLATE I





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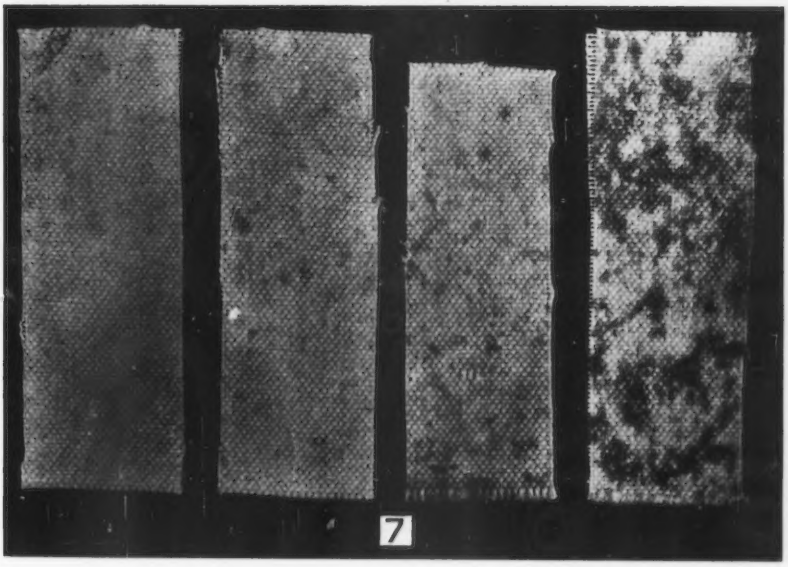
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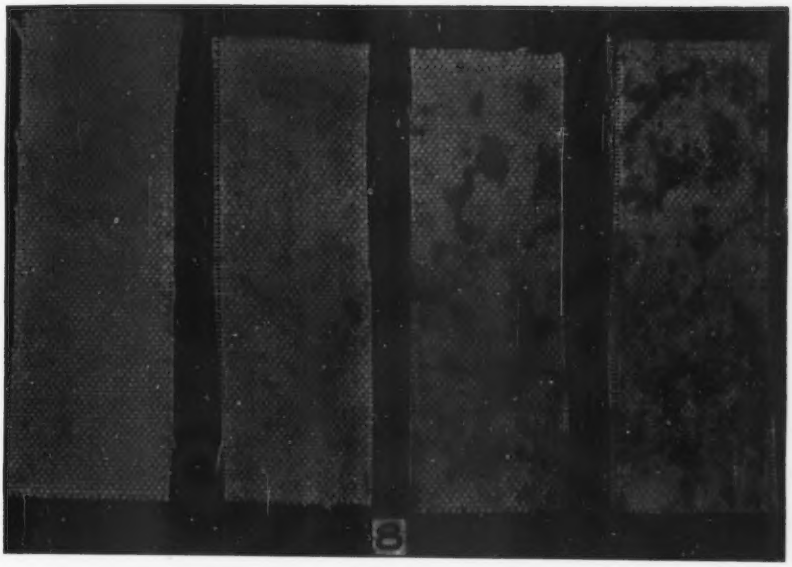
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AN APPARATUS FOR THE BUTT-WELDING OF FINE WIRES[1]

By L. D. Armstrong[2] and T. M. Dauphinee[2]

Abstract

A butt-welding apparatus employing a condenser discharge is described. This apparatus was developed for welding thermocouples of small dimensions but is suitable for most types of fine wires. The welding characteristics and possible applications are given in detail.

During a recent investigation of the thermal conductivity of metals it was necessary to weld a large number of fine wires of several different materials. For this purpose flame welding was inconvenient and the finished joints were not always satisfactory; in particular, the resultant joint was almost always considerably larger in diameter than the original wires, and for some applications this was highly undesirable. In addition, flame welding could not be used with certain materials. In order to overcome these difficulties a method of butt-welding by means of an electrical discharge was developed, and it proved to be very satisfactory.

Apparatus

In order to obtain an apparatus in which the time of heating would be kept short and in which, thereby, the extent of the wire heated and the amount of oxidation would both be kept to a minimum, the energy for the welding was obtained from the discharge of a bank of condensers. This principle of a condenser discharge has been used in the spot welder of Copeland and Rothschild (1), and to some extent commercially. The successful operation of the apparatus as finally developed depends on a suitable adjustment of four variable quantities; viz., capacity, potential, resistance, and polarity.

A photograph of the apparatus is shown in Fig. 1 and a schematic diagram of the electrical circuit in Fig. 3. The condensers (*a*) are connected through switches (*b*) in such a way that any capacity between 5 and 600 μf. can be selected, and are charged to the desired potential by means of a 300 v. power supply (*c*) connected across a potentiometer (*d*). The discharge passes to the welding clips (*e*) through a push-button switch (*f*) and an adjustable series resistance (*g*), which serves to vary the time constant of the discharge. A reversing switch (*h*) changes the polarity on the clips. The wires to be welded are clamped in the spring jaws of the clips, one of which is fastened rigidly to the base of the apparatus, while the other is mounted in such a way that it can be moved in three mutually perpendicular directions, two of them in the focal plane of the viewing microscope (Fig. 2). By this arrangement the position of one wire relative to the other can be easily and accurately adjusted.

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[2] *Physicist.*

Method

The method of butt-welding the wires is, briefly, as follows. The wires, the ends of which have previously been cut off with a sharp edge, are placed in the clips and aligned in the field of the microscope. The circuit constants (capacity, potential, resistance, and polarity) having been set to the values required for the specific size and type of wires, the two wires are brought together, with the push-button switch closed. The resultant spark discharge melts the ends of the wires into two ball-like tips, the appearance and size of which depend on the circuit constants. After any necessary adjustments have been made, the tips are brought together again, when, depending on the material of the wires, either the weld takes place or the two balls stick together. If the latter occurs, the balls are pulled apart and the weld is completed on the next approach. Photographs showing successive stages of the welding process are shown in Fig. 4.

The values of the circuit constants used are quite critical and have been experimentally determined for the particular wire combinations. Some representative values for different types of welds are given in Table I. The

TABLE I

EXAMPLES OF CIRCUIT CONSTANTS FOR TYPICAL WELDS

Clip No. 1	Clip No. 2	Capacity, μf.	Potential, v.	Resistance, ohms	Polarity	Description
0.003 in. platinum	0.003 in. platinum	10	225	¼	—	Weld on third approach
0.005 in. platinum	0.005 in. platinum	70	140	3	—	Same as above
0.005 in. platinum	0.003 in. platinum	40	120	0	No. 2 pos.	First approach
		50	120	¼	No. 2 pos.	Succeeding approaches
No. 32 copper	No. 32 copper	120	160	1	No. 1 pos.	First approach
		120	180	1	No. 2 pos.	Succeeding approaches
No. 36 chromel	No. 36 chromel	70	100	½	—	Usually welds on second approach
		70	100	1		
0.003 in. platinum	No. 36 copper	64	90	1½	No. 1 pos.	First approach
		80	90	1½	No. 1 pos.	Succeeding approaches
No. 36 copper	No. 36 chromel	60	140	1½	No. 2 pos.	First approach
		60	140	¾	No. 2 pos.	Second approach

apparatus as designed at present is not suitable for welding wires larger than No. 28 B. & S. gauge. All the common wire materials have been welded successfully (alumel, chromel, constantan, copper, gold, manganin, nickel, and platinum) although difficulty has been encountered in welding tungsten.

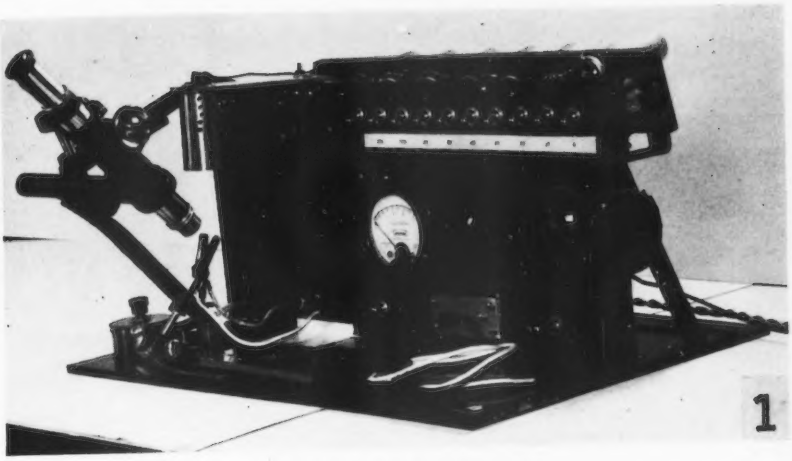

FIG. 1. *Butt-welding apparatus.*

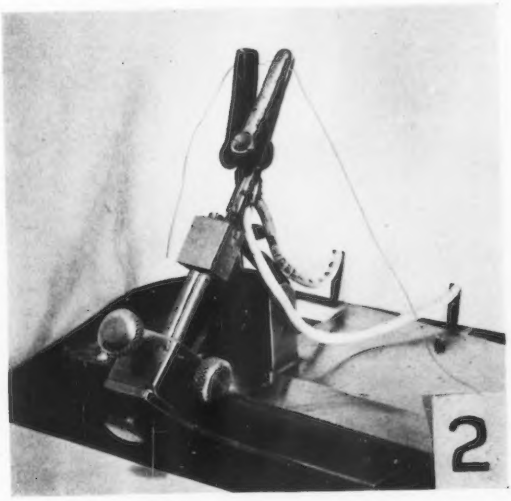

FIG. 2. *Three-way adjustable clips.*

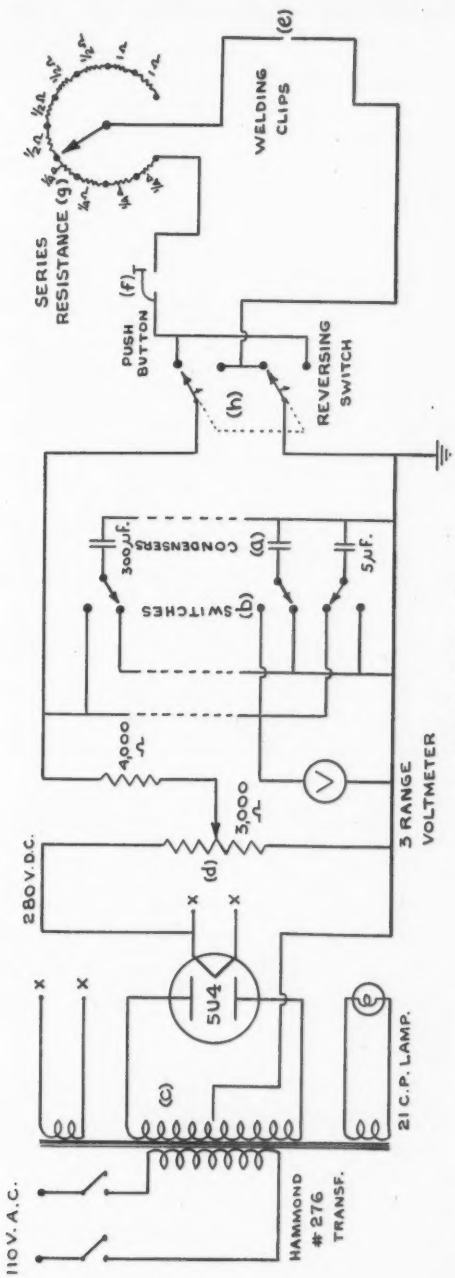

FIG. 3. *Wiring diagram.*

Properties and Applications of the Welds

Welds obtained by this method have several very desirable properties. The diameter of the welded portion is only slightly greater than that of the wires being welded and there are no sharp projections. This permits welded wires to be threaded through fine bore ceramic tubing and rubber vacuum seals. Despite their small size the welds have considerable mechanical strength and will withstand pulling and bending better than the original wires. Both the extent of the heated section and the duration of the heating are kept to a minimum, with great reduction of the amount of oxidation and annealing.

One advantage of the method is the ease and consistency with which good welds can be made. The microscope and positioning clips make aligning of the wires both convenient and accurate, and in addition the microscope offers a quick check of the weld. No particular shaping of the ends of the wires is required. Moreover, wires dissimilar in composition and size can be welded with no additional difficulty.

One of the most valuable features of the welds is the negligible thermoelectric effect in a join between two pieces of the same material. This is probably due to the small extent of the heated section and the minimized oxidation. Although temperature gradients of up to 80° C. per inch have been applied across the weld, no significant difference has ever been noted between the thermoelectric behaviour of the welded wires and unwelded wires subjected to the same conditions. Experiments have indicated that for 0.005 in. platinum or platinum – 10% rhodium, annealed before welding, the thermal effect in a weld with a 70° C. per inch gradient across it is not more than a few tenths of a microvolt, and is probably much less. Similar results have been obtained for transitions from 0.003 to 0.005 in. This neutrality of the welds makes it possible to reduce the resistance and increase the strength of lead wires by making transitions from one size to another even in regions of appreciable temperature gradient.

Although this method of welding was originally developed to make fine thermocouple junctions, the excellent characteristics of the welded joints and the ease and consistency with which they can be made have led to many other applications. To date, the apparatus has been put to the following uses:

1. Making thermocouple tips of very small dimensions.
2. Making repair joints in thermocouple leads that can be threaded through fine bore tubing and rubber vacuum seals.
3. Connecting lead wires in difficult locations by the use of portable extension leads and clips.
4. Connecting heating or thermocouple wires to low resistance lead wires, either by changing materials or by varying the diameter.
5. Repairing fine copper wire in coils without introducing discontinuities.

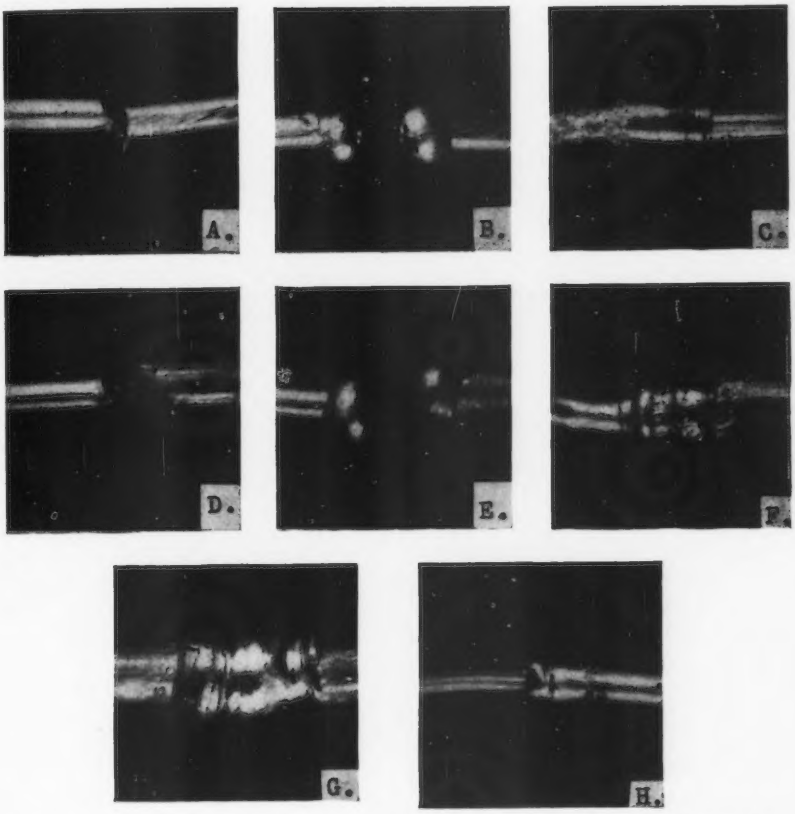

FIG. 4. *Various stages of typical welds. A, B, and C. Stages in welding 0.005 in. platinum to 0.005 in. platinum. D, E, and F. Stages in welding 0.005 in. platinum to No. 32 (B & S) copper. G. Completed weld between two No. 32 (B & S) copper wires. H. Completed weld between 0.003 in. platinum and 0.005 in. platinum wires.*

6. Making three-way joints for potential leads. The making of other special types of joints should be possible.
7. Making very smooth round tips for the stylus of a recorder using Teledeltus electrical recording paper. This was accomplished by using the first stage of the process with platinum wire.

Conclusion

The apparatus described offers a very useful method for welding wires of the smaller sizes, and with suitable modifications should prove applicable to wires of the larger sizes as well. The simplicity of construction and relative cheapness of the materials put it within the reach of any laboratory.

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PORTABLE GEIGER-MÜLLER COUNTERS[1]

By W. Hushley[2] and K. Feldman[2]

Abstract

Three models of portable Geiger–Müller counters which were found useful in the detection of radioactive minerals are described. The models are similar in that in each the high voltage for the Geiger–Müller counter tube is supplied by means of a multivibrator circuit and the pulse from the G–M tube is fed to a trigger circuit which actuates headphones. In one model a neon tube discharge circuit is used to give one headphone pulse for every 10 from the G–M tube and a counting rate meter is provided. Details of circuit design and application are given. The circuit of a simple amplifier that may be used with a G–M tube at the end of a long three-conductor cable is given.

General Description

Several models of portable Geiger–Müller counters which are of light weight and low power consumption were developed to meet the need for detectors of radioactive minerals suitable for field use. Three of these are described here. Their circuits, which were suggested by those published previously by others (1, 2, 3), are given in detail.

The three models *A*, *B*, and *C*, Figs. 1, 2, and 3, have a number of basic similarities. They all use self-quenching Geiger–Müller counter tubes, operated at about 1000 v. This high voltage is supplied by the same type of circuit in each case. The pulses from the G–M tube actuate trigger circuits which in turn operate the headphone and rate meter circuits.

The high voltage circuit referred to above is similar to one suggested by Huntoon (3). It consists essentially of a multivibrator with an inductive load in the plate circuit of one tube and a rectifier through which the pulses induced in the inductance charge a condenser. Negative high voltage is used, making it possible to have all the filaments near ground potential. Thus a single "A" battery may be used and the diode contained in the envelope of one of the multivibrator tubes may be used as a rectifier. The voltage to which the condenser becomes charged approaches the peak value of the pulses induced in the inductance. In each of the models described, the multivibrator has one voltage amplifier and one power amplifier type of tube with the inductance in the circuit of the latter. The power amplifier tube permits the use of low "B" battery voltages. Power requirements are reduced by using the screen grid rather than the plate of the power amplifier tube for multivibrator action. The frequency of the multivibrator is about 40 oscillations per sec. This oscillation is heard as a low hum in the headphones of Models A and B and is an indication that the high voltage section of the instrument is functioning.

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[2] *Physicist.*

Because of the normal variations from rated values of commercial resistors and condensers, differences in the performance may be expected in individual instruments of the same model. This is of significance chiefly in the performance of the high voltage circuit in which differences in the characteristics of the electron tubes also have considerable effect. It is often necessary to match the tubes with the remaining components of any instrument to obtain the desired range of high voltage. Differences in electronic tubes of the same type are discussed at greater length below. The 1S4 tube in Models A and C may be replaced by the 3Q4 or 3S4.

The trigger circuit consists of tubes V3 and V4 with the necessary components. The latter tube is biased beyond cut-off and a negative pulse from the G–M tube produces a single oscillation of the trigger circuit. Equalized pulses are thus available to actuate the headphones and the counting rate meter.

Model A

This model, which has headphone detection only, was designed to serve as a prospector's instrument. It may be used continuously for many hours and the batteries do not need to be replaced very frequently. The instrument weighs about 6 lb.

A circuit diagram of Model A is given in Fig. 1. Tubes V1 and V2, a 1S4 and 1S5, respectively, and their associated components comprise the high

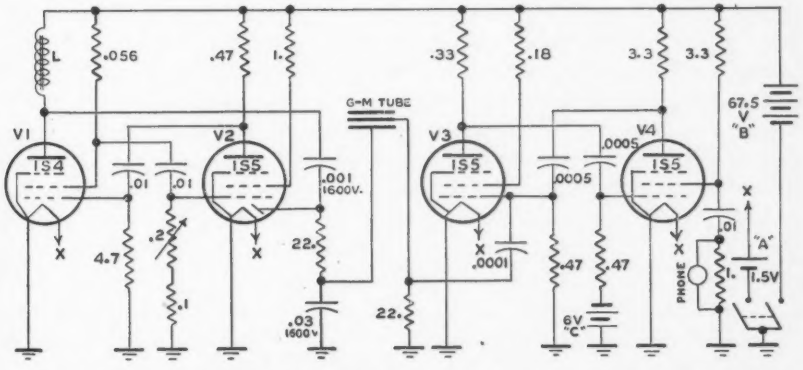

FIG. 1. *Circuit of portable Geiger–Müller counter, Model A. Resistances are given in megohms, capacities in microfarads.*

voltage section. The values of the capacities and resistances to give the desired high voltage range depend chiefly on the type of inductance L, on the particular tubes used and on the "B" battery voltage. The "B" voltage is supplied by a 67½ v. battery. The inductance used in Fig. 1 is provided by a 150 henry filter choke (Hammond No. 150, chosen for its availability and moderate weight), although, in general, audio plate reactor inductances are more efficient than filter choke inductances. The choice of condensers was

determined by their physical size as well as their capacity. The grid and plate resistor values are not critical but it is desirable to choose that combination which is least sensitive to the individual characteristics of electronic tubes and which keeps the "B" battery current near the minimum. The high voltage may be adjusted by means of the variable resistor in the control grid circuit of V2 to give a normal range from 800 to 1300 volts. Since the G–M tubes used have an operating range of about 200 v. it is not difficult to adjust the high voltage to a suitable operating value. The high voltage decreases as the "B" voltage decreases but increases as the "A" voltage decreases. These changes may be as high as 20% for the usable battery ranges. By choosing "A" and "B" batteries of appropriate capacities these effects may be made to compensate each other to some extent, and the high voltage will be almost independent of the ageing of batteries due to use.

The high impedance headphones may be operated from the screen grid or the plate of the tube V4, the pulse being louder when the phones are on the screen grid. While this instrument was designed for use where a rate meter was not considered to be advantageous, a simple rate meter (2) may be easily added by inserting a microammeter in parallel with an electrolytic capacitor in either the plate or the screen grid circuits of V4. The headphone may then be placed on the screen grid of V3 where the hum due to the high voltage ripple is louder but still not objectionable.

The "B" battery drain, which depends chiefly on the design of the high voltage circuit, is about 0.75 ma. If one uses the batteries Eveready No. 742 (1.5 v.) and No. 467 (67.5 v.) in the instrument six hours daily, the former lasts about 20 days and the latter about 40 days. Bias voltage is supplied with 'Penlite' cells.

The G–M tube used has a cathode cross-section of 2 by 6 cm. and a normal background rate of about 40 pulses per min. It was found that this pulse rate is about optimum for aural detection. An increase in the counting rate of about 50% above background is readily detectable.

Model B

The circuit of Model B, shown in Fig. 2, is similar to that of Model A. Model B, however, was designed to meet the need of a very small and light-weight instrument that would be used only intermittently.

The electronic tubes used are of the subminiature type, Raytheon 2E35 and 2E41, the former being a power amplifier tube. The tubes V1 and V2, Fig. 2, are used to develop the high voltage for the G–M tube and tubes V3 and V4 are used in the trigger circuit. Two 'Penlite' cells and two hearing-aid type batteries are used as the "A" and "B" supplies, respectively. The inductance L is a small 200 henry audio plate reactor (U. T. C. No. 0-13).

No provision is made for the manual control of the high voltage. The voltage obtained in any unit may be adjusted by altering the screen grid resistance of V1 or the control grid resistance of V2. With the constants

given in Fig. 2, voltages of about 1000 volts may be expected. As in Model A the high voltage is very sensitive to the "A" and "B" voltages, and not all tubes prove satisfactory in the high voltage section but the unsatisfactory ones usually may be used in the trigger circuit. Each of the tube types used in the model requires a filament current of 30 ma. while the total "B" battery drain is about 0.7 ma.

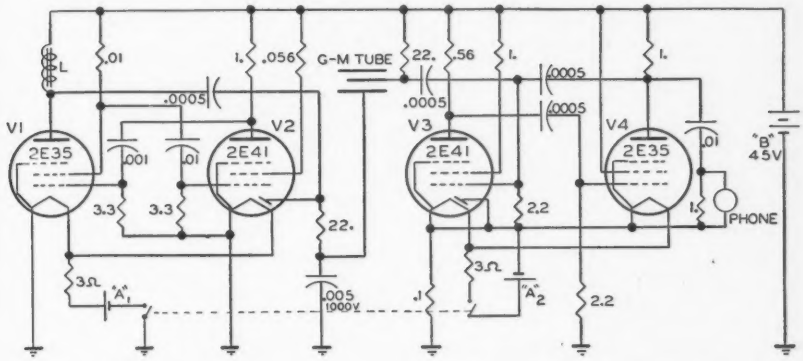

FIG. 2. *Circuit of portable G–M counter, Model B. Resistances are given in megohms, capacities in microfarads.*

As made here, the headphone and the G–M tube are both built into the chassis making the unit completely self-contained. The small G–M tube used has a normal background count of about 10 pulses per min. Using two 'Penlite' cells for the filament batteries and two Eveready No. 412 batteries for the "B" supply, the instrument may be built into a container 1 by 3 by 6 in. and will weigh approximately 1 lb. With intermittent use the batteries mentioned above will last several hours.

Model C

Model C was designed to serve as a more precise instrument for the measurement of γ-ray intensities as, for example, in surveying radioactive areas, assaying in the field, etc. It includes a counting rate meter as well as headphones. The circuit diagram is given in Fig. 3. For field work this instrument is normally used with three G–M tubes in parallel, each with a cathode 2 by 15 cm. in cross-section. The high voltage section of this model is identical with that of Model A. The trigger circuit is also somewhat similar except that tube V3 is used to operate the headphone circuit while V4 operates the counting rate meter circuit.

In the headphone circuit, the pulses from the trigger circuit cause the condenser in series with the neon tube V7 to charge through the diode of V3. When this charge becomes great enough the neon tube fires, discharging the condenser and giving a report in the phones. With the constants given,

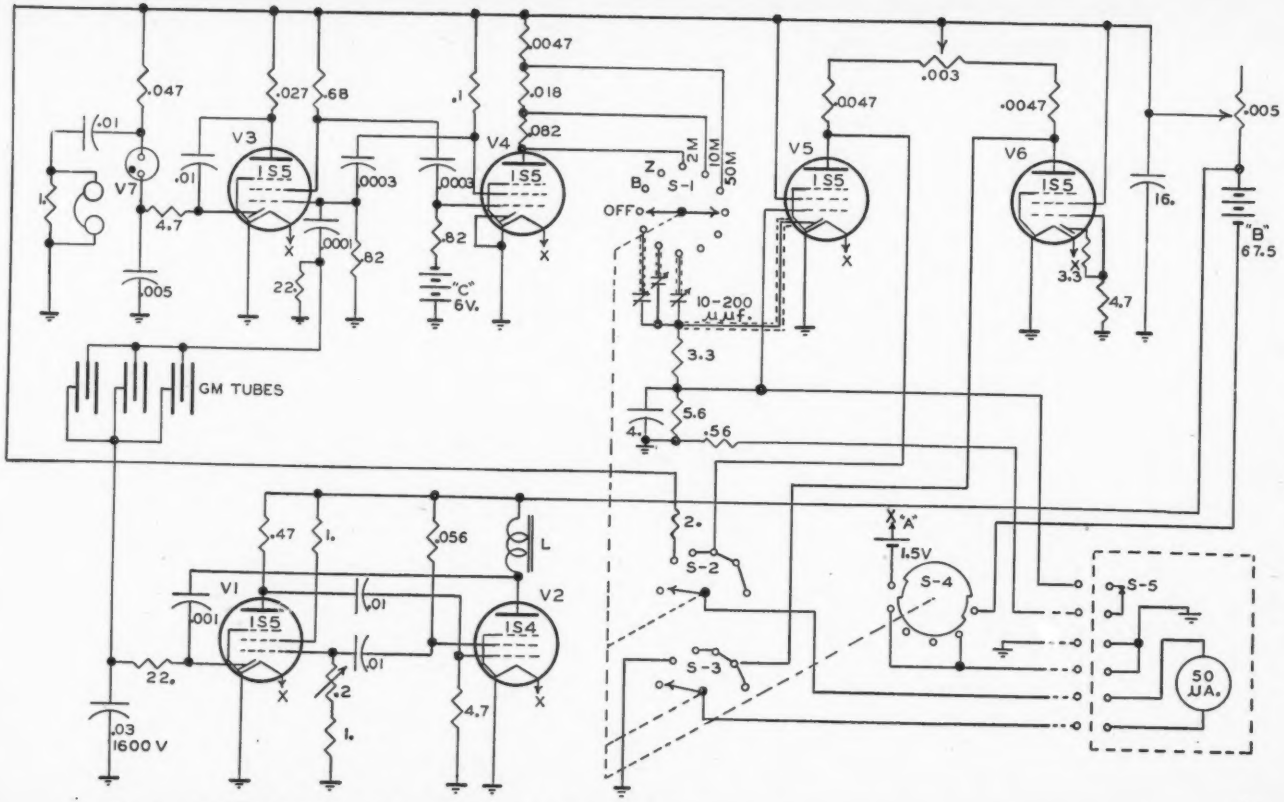

FIG. 3. *Circuit of portable Geiger–Müller counter, Model C. Resistances are given in megohms, capacities in microfarads.*

about 10 pulses from the G–M tubes give one pulse in the phones at low counting rates. This 'scaling factor' may be altered by changing the capacity of the condenser in series with the neon tube, the "B" voltage applied to the neon tube, or the characteristics of the trigger circuit. At higher counting rates the scaling factor increases and when the counting rate approaches 10,000 per min. the pulse rate of the neon tube reaches its limit. A scaling-down of the pulse rate is necessary when G–M tubes with large cross-sectional areas are used, since then a normal background count of several hundred pulses per minute may be expected and without scaling it down it would be difficult to recognize significant changes aurally. The random fluctuations in the pulse rate are also averaged out to some extent and this makes aural detection easier. This feature is of value in searching for radioactive minerals, since it allows the operator to depend predominantly on the phones for an indication of the γ-ray intensity while giving him freedom to concentrate visually on other things.

The counting rate meter has a long time constant so that reasonably steady readings are obtained even at the background counting rate. The meter reading is almost linear with pulse rate so that it may be used for quantitative comparisons. The rate meter consists of a balanced bridge circuit using two pentodes (1). By rectifying the pulses from V4 through a diode, negative charge is collected on the R–C grid circuit of V5. This causes a change in the plate current which gives a reading on the meter connected between the plates of V5 and V6. A simple analysis of the two-tube balanced circuit is given below to show that its sensitivity to the grid voltage depends on the transconductance of the first tube and the ratio of the load resistances of the two tubes. The meter reading is set to zero with the selector switch in the *Z*-position by means of the variable resistor in the plate circuit of V5 and V6. With the selector switch in the positions labelled 2M, 10M, and 50M, full scale deflection is obtained on the meter for 2000, 10,000, and 50,000 pulses per min., respectively. The final adjustment for these ranges is made by means of the variable (padder) condensers in the coupling circuit. By means of the push button switch S-5, the 4 μf. condenser may be discharged and the meter reading brought down rapidly to zero or any other desired value.

Because the operation of the rate meter, trigger, and headphone circuits is sensitive to the "B" battery voltage, this voltage is maintained at 58 v. for these circuits by means of the variable resistor in series with the "B" battery. The adjustment is made with the selector switch in the *B*-position and the voltage is read on the meter. The batteries used in this model are the same as those in Model A. The total "B" drain is approximately 3 ma.

For field work this model is fitted with the meter and the push button switch in a small meter-box at the end of a cable. A cable connector at the meter-box may be used as an On-Off switch. The meter-box is worn on a waistband while the main part of the instrument is carried in a canvas carrying case on the back of the operator. The complete unit weighs about 11 lb.

FIG. 3. *Circuit of portable Geiger–Müller counter, Model C. Resistances are given in megohms, capacities in microfarads.*

Analysis of Balanced Bridge Circuit

The following analysis shows the relation between the meter current and the applied grid voltage in the rate meter circuit described above. Referring to Fig. 4, let I_1, I_2, I_3, I_4, I_m be the current through R_1, R_2, T_1, T_2, R_m, respec-

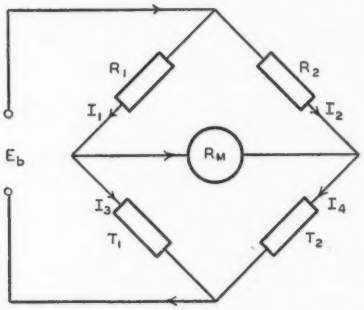

FIG. 4. *Schematic diagram of counting rate meter circuit used in Model C.*

tively, and let the added subscript 0 indicate the current when $I_m = 0$. If k is defined by

$$k = \frac{R_1}{R_2} = \frac{I_{20}}{I_{10}} = \frac{I_{40}}{I_{30}}, \tag{1}$$

then application of Kirchoff's laws shows that

$$I_m = \frac{I_4 - kI_3}{k + 1 + R_m/R_2}. \tag{2}$$

In the rate meter circuit, R_m is the meter resistance and if $R_2 \gg R_m$ then approximately

$$I_m = (I_4 - kI_3)/(k + 1). \tag{3}$$

If I_3 and I_4 are written $I_{30} + \triangle I_3$ and $I_{40} + \triangle I_4$ then Equation (3) becomes

$$I_m = (\triangle I_4 - k \triangle I_3)/(k + 1). \tag{4}$$

Let the two components T_1 and T_2 be vacuum tubes and let the grid potential of T_1 be changed by $\triangle E_c$ while T_2 is left unchanged. Then $\triangle I_4 = 0$ and $\triangle I_3 = G_m \triangle E_c$ where G_m is the transconductance of T_1 and is assumed constant. Equation (4) then becomes

$$I_m = - G_m \triangle E_c k/(k + 1). \tag{5}$$

For a balanced circuit with equivalent components this simplifies to

$$I_m = - \tfrac{1}{2} G_m \triangle E_c.$$

Thus the meter current I_m is a linear function of the grid voltage E_c and is independent of the absolute values of the load resistances. However, the latter should be high compared to the meter resistance to maintain sensitivity.

The linearity of the rate meter depends on the collecting circuit which determines E_c and on the transconductance of V_5 remaining constant.

If the tube T_2 is replaced by a resistance R_4 then

$$\triangle I_4 = I_m R_2/(R_2 + R_4) ,$$

and

$$I_m = - G_m \triangle E_c \frac{k}{k+1} \left[\frac{1}{1 - R_2/(R_2 + R_4)(k+1)} \right] . \qquad (6)$$

From Equation (6) it may be seen that the use of a divided resistance for half of the balanced circuit results in increased sensitivity. Replacing the vacuum tube by a resistance also reduces the filament current required, but it has the disadvantages that the zero-set of the meter is very sensitive to the "B" voltage, and the time lag in the filament emission when the instrument is turned on may cause a surge of current through the meter.

Electronic Tubes for the High Voltage Circuit

Tests were made on about two hundred 1S4 and 1S5 electronic tubes to determine their suitability for use in the high voltage circuits described in this paper.

The 1S4 tubes were from two lots made by different manufacturers and were tested in a given circuit of the type described for Models A and C, with a given 1S5 tube. Under the fixed conditions 25% of one lot and 35% of the other gave a maximum high voltage of less than 1000 v. while 60% of the first lot and 45% of the second gave above 1100 v. There seemed to be little correlation between the maximum high voltage and the range over which it could be varied by means of the high voltage control.

The 1S5 tubes were from three lots made by different manufacturers. In this test the tubes were classified as good, fair, and poor, according to their general performance, such as maximum high voltage obtained and the rate of leakage of charge after the instrument is turned off. The results obtained are given in Table I.

TABLE I

CLASSIFICATION OF 1S5 TUBES IN HIGH VOLTAGE CIRCUIT

Classification	Lot 1	Lot 2	Lot 3
Good, %	10	50	85
Fair, %	15	25	10
Poor, %	75	25	5

This table points out a serious disadvantage in using this type of high voltage supply in that satisfactory performance depends a great deal on the particular lot of electronic tubes being used. In one test the diodes of the 1S5 tubes were used independently of the pentodes. The test showed individual variations in high voltage of as much as 150 v. for diodes that showed no other

irregularities such as excessive leakage or breakdown. On the average, potentials in excess of 1500 v. are required to cause breakdown in the diodes. The performance of the 1S5 tubes in the circuit does not depend, however, on the diode alone.

The results given are typical of other tube types such as 3A8GT, 1D8GT, and 2E41. When a group of satisfactory tubes are classified in order of merit as tested in a given high voltage unit, this order is not necessarily the same in another unit. However, poor tubes are usually not good in any high voltage unit though they may generally be used in the trigger sections of the instruments.

Amplifier for Geiger–Müller Counter Probe

It is sometimes necessary to use a G–M counter tube in a probe at the end of a long cable. The capacity of the cable reduces the amplitude of the voltage pulse from the G–M tube and it is necessary to use an amplifier in the probe end of the instrument. Fig. 5 shows a circuit that may be used with a three-conductor cable. The probe contains only the G–M tube, an electronic tube,

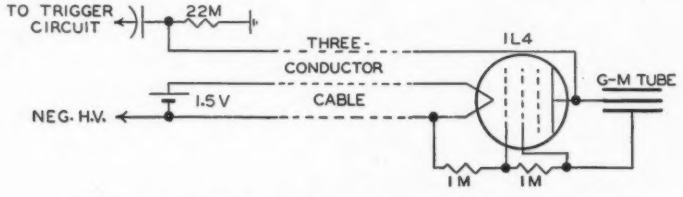

FIG. 5. *Circuit of an amplifier for a Geiger–Müller counter probe.*

and two resistors. The current drawn from the high voltage supply is about 1 μa. Such an amplifier has been used at the end of 1000 ft. of three-conductor 'cab-tire' cable in a portable counter designed for surveying diamond-drill holes.

Effect of Temperature on Portable Counters

Low temperature will affect the operation of the counters described here by condensing the organic vapour in the self-quenching G–M tubes and by reducing the efficiency of the batteries. The first effect can be eliminated by using an organic compound such as ether, which does not condense at the temperatures at which counters are normally used. The reduced efficiency of the "A" battery causes an increase in the high voltage which is compensated by the effect of the lower "B" battery voltage. The net result is usually some increase in the G–M tube voltage. If the change in temperature is accompanied by the condensation of moisture in the instrument the high voltage will be reduced considerably. Most of the instruments made here were not used in areas of high relative humidity and effects of humidity were not considered in their design.

Acknowledgments

The authors wish to acknowledge the assistance received from other members of this laboratory in the design and construction of portable Geiger–Müller counters.

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A LABORATORY SHAKER[1]

By W. Harold White[2]

Abstract

A laboratory shaker is described that employs an eccentricless drive. The machine has sufficient flexibility in design to permit variable temperature and speed control. It has a capacity of two dozen 500-ml. flasks.

Introduction

Several years ago, a survey of existing laboratory shaking apparatus showed that an efficient machine of large capacity, suitable for certain types of food analysis, was commercially unobtainable. Special requirements, notably sufficient flexibility in design to permit variable temperature and speed control, prompted the designing of a machine embodying temperature maintenance at approximately 100° C., speed variation by means of cone pulleys, capacity for two dozen 500-ml. flasks, and a drive that does not depend upon eccentric motion. The present article has been prepared in response to requests for details of construction.

Details of Construction

The apparatus shown in Fig. 1 did not make use of the usual eccentric drive, since it was found that eccentric motion produced too abrupt a movement, particularly at high speeds. This obstacle was overcome by using the Eureka–Buhler 'eccentricless' drive,* consisting of two counterweighted steel wheels enclosed in drums, shown at *B* in Fig. 1, supported by a base-plate, *L*, and geared to rotate in opposite directions. The counterweights were so arranged that when they were in the vertical plane the centrifugal forces exerted by their rotation were equal and opposite, whereas when they were in the horizontal plane the forces were additive and produced a shaking motion.

Length of body travel is dependent upon the speed used and the weighting of the steel wheels at the factory; a travel of $\frac{1}{2}$ in. at the lowest speed was found to be most suitable for normal needs. As the speed of the shaker depends upon the speed of rotation of the steel wheels, variation may be obtained by changing the ratios on the cone pulleys at *C* and *K*, side view at *D*. Power was supplied by a 1/6 h-p. electric motor, *C*.

The apparatus may be mounted upon castors for mobility, as shown, or permanently established on wooden blocks.

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Contribution from the Division of Applied Biology, National Research Laboratories, Ottawa. Issued as Paper No. 191 of the Canadian Committee on Food Preservation and as N.R.C. No. 1527.

[2] *Formerly Biochemist, Food Investigations; at present, Research Chemist, Imperial Oil Co. Ltd., Sarnia, Ont.*

* *Obtained from S. Howes Co., Inc., Silver Creek, N.Y.*

The supporting framework was constructed from $1\frac{1}{2}$ in. angle iron in the following dimensions: length, 3 ft.; width, 1 ft. 6 in.; height, 2 ft. 4 in.

The body of the shaker was constructed of 1-in. lumber, to form an open-top box 3 ft. 3 in. by 1 ft. 4 in. by $10\frac{1}{2}$ in., outside dimensions. A copper steam chest, 1 in. in height and containing copper steam coils, was fitted into the bottom of the box, covered with a $\frac{1}{4}$ in. layer of felt to avoid damaging glassware, and overlaid with $1\frac{1}{4}$ in. insulation board, with holes of proper diameter to hold flasks of the desired size. These details are indicated in the cut-away section, *I*, in which the top layer represents the insulation board.

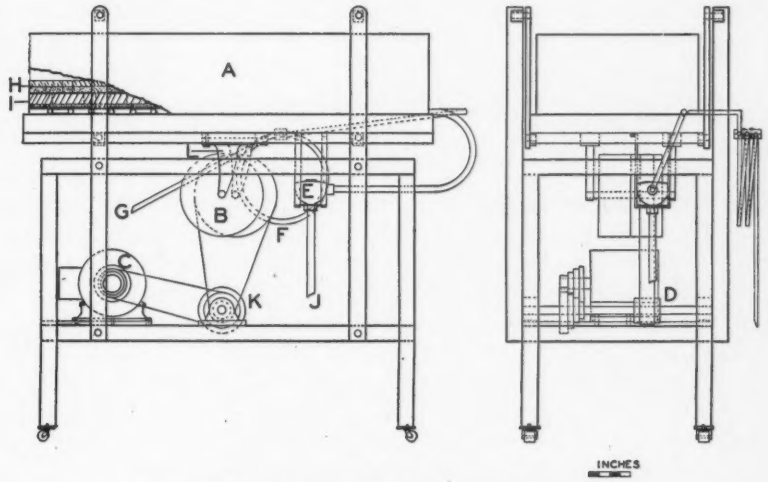

FIG. 1. *Side and end views of a laboratory shaking apparatus.*

A 7/16 in. plywood board cover, fitted with $\frac{1}{2}$ in. felt insulation, is shown in section at *H*, resting on section *I*. This cover, with holes through which the flask-necks protrude, holds the flasks firmly in place.

The body of the shaker was mounted on four sets of bearings, two sets being shown in the end view in Fig. 1. This indicates a $\frac{1}{2}$ in. flat brass bearing at the top of the supporting arm; at the bottom of the arm is a $\frac{1}{2}$ in. rod, connected as an axle to the corresponding opposite arm.

Steam was introduced at *G*, representing the copper tubing inlet, passed through a shock-absorbing coil, *F*, which absorbed the motion produced when the shaker was in use, and thence to the metal steam chest. Returning steam was passed through a steam-trap, *E*, and any condensed water drained off through the outlet, *J*.

Thermostatic control may be installed for temperatures below 100° C., by circulating water from a temperature controlled reservoir in place of steam.

A LARGE CYLINDER AND TAPER COMPARATOR FOR GAUGE MEASUREMENT[1]

By R. H. Field[2]

Abstract

The measurement of the diameters of cylinders and cones is an important feature in gauge manufacture and inspection. High accuracy is essential in this work, as the objects measured may be employed as limit gauges for use in the inspection of other precision gauges to which direct means of measurement cannot be applied. A comparator for accommodating cylinders or cones with maximum diameters of 12 in. and lengths up to 48 in. was designed and constructed during Great War II at the National Research Laboratories, Ottawa, and used throughout the war. In preparing the design special consideration was given to ease of construction and no ultra precision grinding or difficult fits were involved.

Introduction

It is the usual practice to measure the diameters of cylinders or cones, in the metrological laboratory, with the object standing vertically (the small diameter downward in the case of cones) while micrometer measurements are made across the outside of two small horizontal cylinders contacting the object and resting on the tops of vertical end-bars (1, page 89). While this operation can be carried out with the aid of a hand-held micrometer caliper, considerable skill is necessary on the part of the operator, who, moreover, has to work under uncomfortable conditions. Even then, a precision of measurement better than 0.001 in. is difficult to attain. To make the operation easier to perform and to increase the precision to conform to modern requirements in engineering practice, a range of comparators was designed by the National Physical Laboratory, England, to be used exclusively for measuring the diameters of cylindrical and conical objects. These instruments permitted readings to be estimated to 0.00001 in. or 0.00002 in. The N.P.L. kindly supplied working drawings of these instruments to the National Research Council, and two of the smaller (bench type) comparators were constructed to these drawings, with slight modifications. For the large size the N.P.L. scheme entails somewhat difficult shop work during construction, and it was felt that an alternative design would not only make possible improvements in the operation, but would present fewer difficulties in the shop. Therefore, when war needs became urgent, the comparator here described was designed by the author, and constructed in the Instrument and Model Shop of the National Research Laboratories.

[1] *Manuscript received November 20, 1946.*

Contribution from the Division of Physics and Electrical Engineering, National Research Laboratories, Ottawa, Canada. Issued as N.R.C. No. 1533.

[2] *Metrologist, Head of Metrology Section.*

Description

An illustration of the complete instrument is reproduced in Fig. 1. The over-all height is 72 in., the maximum diameter which can be accommodated is 12 in. and the anvils can be set at any height in the range of 1.5 in. to 48 in. above the top of the base. In use the comparator is supported on a heavily built stool 18 in. high, so that the lower ends of the objects being measured are accessible.

Fig. 2 shows the lower portion of the comparator and some details not visible in Fig. 1, while Fig. 3 illustrates the micrometer carriage and its support, which can be set and used over a range of heights. In the view the parts in question are shown dismounted from the comparator and from one another.

Base

The complete assembly is carried by a cast-iron base-plate having a boss at the rear bored to receive the turned lower end of the column supporting the measuring unit, and three flat bosses fitted with the usual vee, cone, and plane shoes (of hardened steel) for locating the foot-screws of the adjustable table for supporting the object. Two other bosses are fitted with 'safety' pegs in case the table should be accidentally tipped.

The table is a heavily ribbed iron casting, planed at the top. It was intended in the original design to fit a hard steel plate, checkered and lapped on its upper face and held to the iron table by clamps located in vee grooves in the edges of the plate. This plate was not made, and the lapped loose steel plate, seen in Figs. 1 and 2, was found quite satisfactory. The bronze foot-screws, tapped into inserted nuts beneath the table, permit the upper reference surface of the steel plate to be accurately levelled for measuring operations, without making any exacting demands on the machinist at the time of construction.

Column

The column forming a support and guide for the diameter-measuring unit is made from a piece of square bright steel, 1.75 in. diam. with the corners planed to give tracks 0.5 in. wide for the rollers on the vertical sleeve described below.

Sleeve

The measuring unit is carried by the sleeve seen best in Figs. 2 and 3. This sleeve comprises a hollow casting, with planed lugs for two horizontal cold-rolled steel rails, having their sides ground, and it has two crown castings located by spigots and attached by screws at its upper and lower ends. Each crown piece serves to hold four ball bearings, 30 mm. O.D., which contact the tracks formed on the corners of the column. The axles for the bearings are eccentric, permitting close fitting and adjustment of the sleeve without difficulty. By this means the sleeve is allowed to traverse up and down the

column quite easily, with no tendency to bind, but is yet free from 'shake'. Furthermore the eccentric axles permit the supporting rails of the micrometer carriage to be made truly horizontal.

A lug on the upper crown casting has a bronze nut inserted, and this engages the vertical setting screw seen in Fig. 2. The sliding casting on which the screw is located in a journal is a free fit on the column, with a brass shoe bearing against one of its sides when the clamping screw is tightened. Thus the micrometer anvils can be set and held at any desired height above the base. A cable is fastened to the sleeve, and, passing over a pulley on a bracket at the top of the column, is attached to a counterweight in the vertical tube seen to the rear of the column in Fig. 1. A light finger touch on the setting screw is sufficient to raise or lower the whole assembly.

To protect the bearings and rails from dirt, a light metal cover having a hinged door at the front, is located on the two posts seen threaded into the upper rail in Figs. 2 and 3.

Micrometer Carriage

The micrometer head and the indicator are mounted on a carriage having a free horizontal movement of about 1 in. To provide this movement without undue friction, which would falsify the indicator settings, or looseness in fit, which would impair accuracy, the carriage is carried and located by means of ball bearings on the two rails attached to the sleeve. The bearings are mounted on two built-up brackets connected together by a bar at the top, and at the bottom by a slide. This slide, which was part of a discarded instrument used for other purposes, forms a horizontal bed for the brackets carrying the micrometer and the indicator.

Two of the ball bearings carry the weight of the movable carriage, and engage with the upper surface of the lower rail. Two others with vertical axes bear against the front face of the rail, to take the reaction from the weight moment of the overhung carriage. Finally, a pair of bearings with vertical axes at the top of each built-up bracket engages with the vertical sides of the upper rail, leaving a sole degree of freedom for the carriage in the direction of the micrometer-screw axis. As in the case of the sleeve, the ball bearings are all mounted eccentrically to permit easy adjustment and the elimination of lost motion.

The free movement of the carriage is limited by rubber buffers fitted into housings screwed to the ends of the upper rail on the sleeve.

Micrometer System

The micrometer and indicator are each inserted in holes formed in ribbed offset brackets, with split lugs for clamping. These holes were lapped in line at the same time while the brackets were mounted on the bed. As can be seen in Fig. 3, the tee slot in the bed permits the brackets to be clamped rigidly at any desired spacing, for actual measuring purposes.

PLATE I

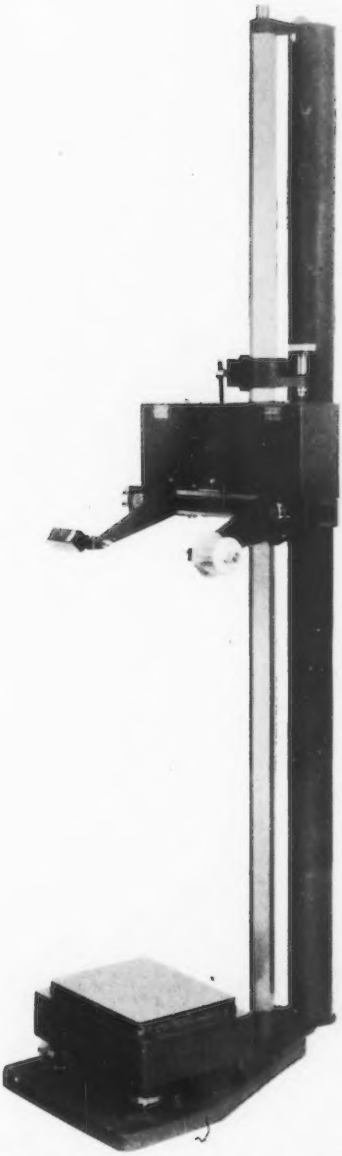

FIG. 1. *The comparator designed and constructed in the National Research Laboratories for measuring large taper and cylinder gauges.*

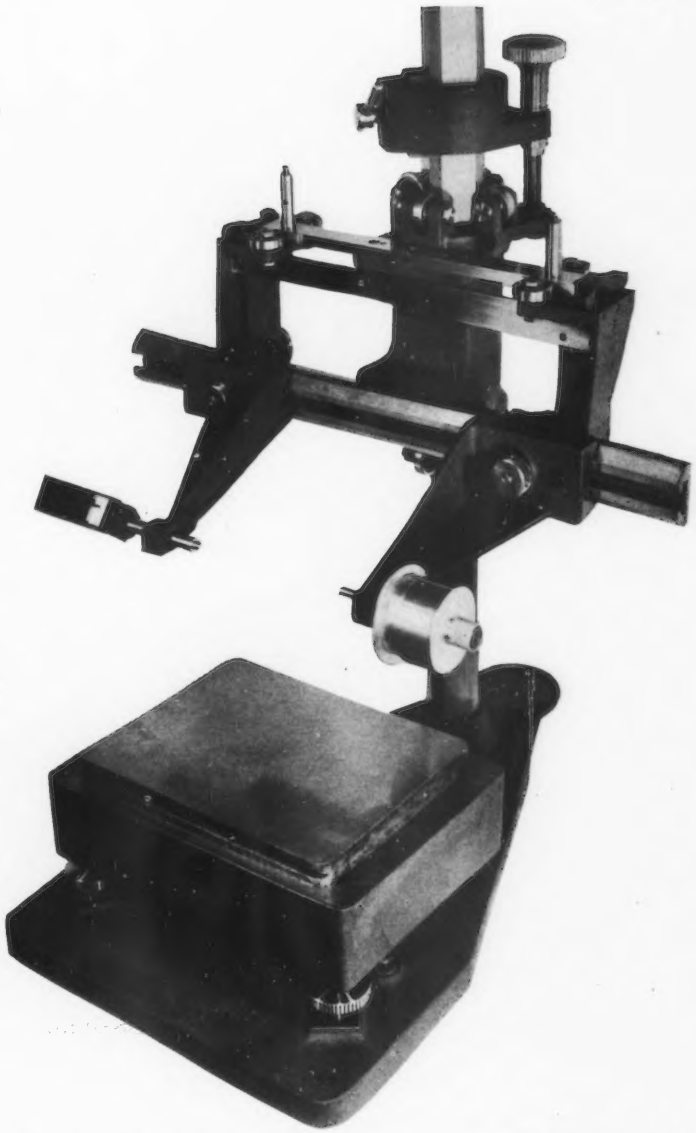

FIG. 2. *Close-up view of the base and micrometer carriage of the comparator, with the cover removed to show the slides and constraints for the movable carriage holding the micrometer head and the indicator, which can be clamped at any desired separation along the grooved bar seen*

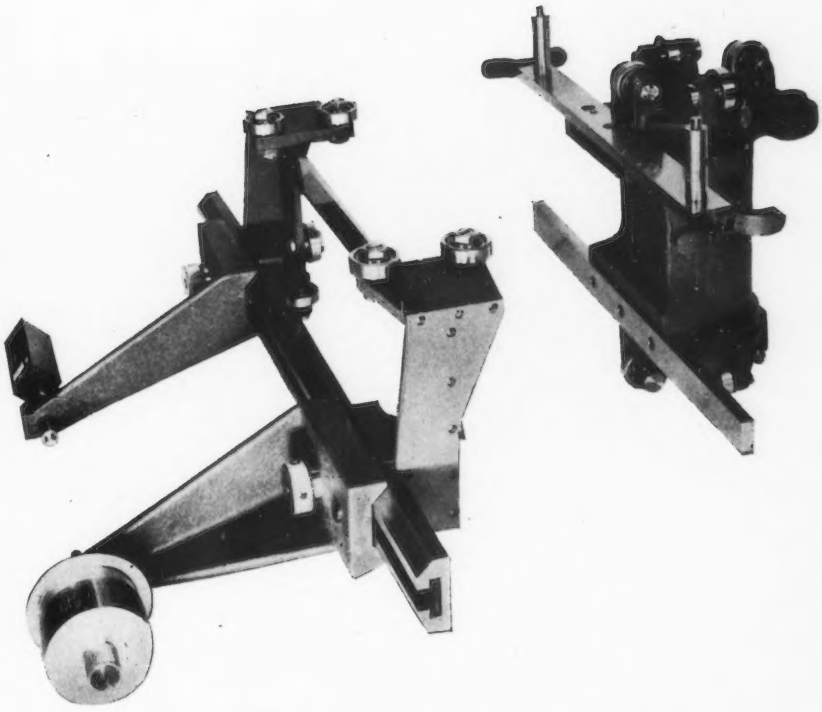

FIG. 3. *Left: The movable carriage dismounted to reveal more details. The ball bearings permit the carriage to be located closely on its two supporting rails and yet to move freely in the axial direction of the micrometer screw.*

Right: The support for the rails holding the carriage. This support travels freely up and down the main vertical guide of the comparator, being located by two sets of four ball bearings, mounted on eccentric arbors to permit easy adjustment and lining up.

For the micrometer a selected and tested commercial micrometer head having a range of 1 in. was fitted with a duralumin drum of 2.5 in. diam. graduated to read directly to 0.0001 in., while a N.P.L. type of indicator, needing a pressure of 0.5 lb. to bring the hand opposite the fiducial mark, was used.

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AN IMPROVED INTERFEROMETER FOR DETERMINING PARALLELISM ERRORS IN LONG END-GAUGES[1]

By L. Graham Turnbull[2]

Abstract

This paper describes an interferometer designed for the determination of the parallelism of the working faces of end-gauges up to 24 in. in length. An instrument for this purpose, but which required somewhat highly specialized technique in the course of its construction, had been previously designed by the National Physical Laboratory. Using optical principles the same as those of the British instrument, another of an entirely new mechanical design has been constructed by the National Research Laboratories, Ottawa. This new interferometer incorporates kinematic principles and a number of interesting features to permit easy adjustment and operation to the very fine limits necessary. By the addition of a sensitive level vial to this instrument, the difference in length of nominally equal end-gauges can be determined to an accuracy of 1 or 2 $\times 10^{-6}$ in.

Introduction

In establishing the length of an end-gauge, complete knowledge of the interparallelism of the gauging faces is of the greatest importance where high precision is required. This is especially true when several gauges are to be wrung together, in which case the derived length of the combination is not the sum of the lengths of the individual gauges, unless the parallelism errors be taken into consideration.

Previous to the outbreak of World War II, the parallelism errors of end-gauges of 3 in. or less in length were determined (absolutely) in the Metrology Section of the National Research Laboratories, Ottawa, by rather laborious interferometric methods; longer gauges were measured by making a large number of comparisons with nominally equal combinations of shorter gauges of known parallelism.

In the National Physical Laboratory, there already existed an instrument known as a Flatness Tester (1), which could be used in the measurement of long end-gauges. In 1940, as the war progressed, the number of gauges of the Johansson type submitted to the National Research Laboratories, Ottawa, rapidly increased, and it was soon realized that (especially in the case of the longer end-gauges) an instrument that could do the same work as the N.P.L. instrument would have to be devised in order to attain more precision and speed in the measurement. The interferometer described in this paper was therefore designed by members of the scientific staff of the N.R.L. to meet this contingency. The basic principle of this apparatus essentially follows that of the N.P.L. flatness tester, but several novel features have been incorporated, and an entirely different mechanical design has been adopted.

[1] *Manuscript received October 10, 1946.*

Contribution from the Division of Physics and Electrical Engineering, National Research Laboratories, Ottawa, Canada. Issued as N.R.C. No. 1534.

[2] *Metrologist.*

Principle

The theory of the interference of light is given in elementary textbooks on physics and optics. It is sufficient to state that when a partially reflecting, optically flat surface (e.g., of quartz or glass) is placed above a second optically flat reflecting surface so as to be nearly parallel to, and almost touching it, interference fringes may be formed. When viewed through the upper plate, these may be seen as a series of parallel, equispaced bands apparently located on the lower surface.

In the parallelism interferometer these interference effects are utilized in the measurement of parallelism errors. Here, an optically flat quartz disk is arranged above the upper optically flat gauging face of an end-gauge in the manner just described. A parallel beam of monochromatic light, passing through a semitransparent mirror which is inclined to the path of the beam, falls normally on to the gauge. If the eye be correctly placed with respect to the mirror so as to receive the reflected rays from the end-gauge, interference fringes may be seen against the background of the gauging face. If then, the gauge be rotated with respect to the flat, through 180° in the plane of its lower gauging face, the spacing of the fringes will alter, unless the working faces of the gauge be co-parallel. The difference in fringe spacing is a measure of the change in the acute angle contained by the plane of the optical flat and the plane of the upper surface of the gauge, and is, hence, a measure of the parallelism error between the gauging faces themselves.

Fig. 1 is a schematic diagram of the optical system of the actual interferometer. In this figure, 1 represents the light source, a mercury arc, rendered reasonably monochromatic by means of a suitable filter, 2. A lens, 3, is used to obtain a sensibly parallel beam of light. Parts 1, 2, and 3 are constructed as a unit, placed outside a small glass window in one of the walls of the temperature-controlled room, in which the parallelism interferometer is located. This separation was made in order to minimize any heating effect that the arc might have on the interferometer, and to exclude from the room the objectionable odours that emanate when the arc is in operation. An adjustable plane mirror, 4, situated vertically above the interferometer, directs the beam of light on to a lens, 5. This lens brings the rays to a focus on a small circular aperture, 6 (approximately 1 mm. in diameter), located centrally in a thin brass diaphragm, 7, which is adjustable with respect to the lens, 5. The last two components constitute a unit that can be adjusted in such a manner that the aperture can be placed at the focus of a lens, 8, which again collimates the beam of light. Interposed between the aperture and lens is a semisilvered plane glass mirror, 9 (which is adjustable), making an angle of approximately 45° to the optical axis. From 8, the rays pass through a quartz disk, 10, the lower face (known as the 'proof-plane') of which is optically flat to about 0.000001 in. Interference fringes are formed between this face and the upper surface of an end-gauge wrung on the working surface of another quartz 'flat', 11, finished to the same degree of flatness as the first. The quartz 'flat', 11, in the case of the Canadian instrument, is set in the

upper end of a vertical cylindrical barrel, described in more detail below, which can be made to rotate in such a manner that the working face of 11 will turn in its own plane or in planes parallel to it. The interference pattern may be viewed through a peep hole, 12, which receives the pattern from the semireflecting face of the glass mirror, 9. A mount, 13, fabricated mainly of brass sheet, contains most of the elements 5 to 12, inclusive.

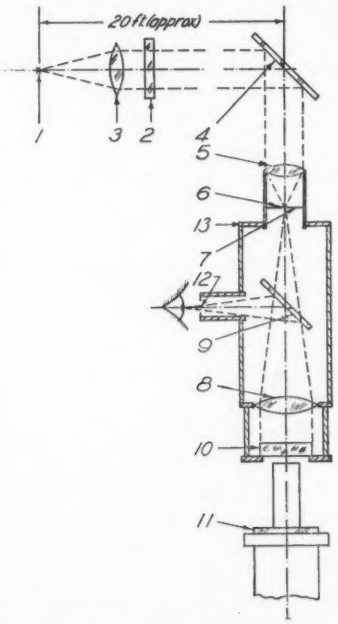

FIG. 1. *Schematic drawing of the optical system of the parallelism interferometer.*

Distinctive Features of the British and Canadian Interferometers

In the British interferometer the turntable is of steel in the form of a disk, with its working faces lapped very flat and accurately parallel. The lower face rests on another equally flat surface formed on the bed of the instrument, so that the upper working face (to which the end-gauge can be wrung) can rotate in its own plane, with very little error. The turntable is constructed of a special high-carbon chrome steel, and is heat treated by the steel maker before lapping. Special technique (i.e., spot grinding) is required to obtain the high degree of precision in flatness and parallelism. The turntable in the Canadian interferometer, on the other hand, requires for its fabrication only such facilities as are available in an ordinary machine shop.

As has been stated above, the turntable of the N.R.L. interferometer consists of a vertical barrel, in the upper end of which is set a quartz base-plate. The working face of this plate can be made accurately perpendicular to the

axis of rotation of the turntable by easy adjustments. In addition, by means of a mirror placed suitably beneath it, the degree of wringing of an end-gauge to the working face can be readily observed and controlled—a feature that has been found to speed up considerably the time involved in the measurements.

Furthermore, in the Canadian instrument the interferometer mount is movable on rollers and is counterweighted so that it can be quickly set into any desired position on a long vertical rod. Moreover, the proof-plane 10 is carried on a platform integral with the interferometer mount.

In the N.P.L. interferometer, the adjustment of fringe spacing and configuration is obtained by tilting the mount which carries the proof-plane, while in the N.R.L. apparatus, coarse adjustment is obtained by tilting the proof-plane itself, and fine adjustment by altering the inclination of the supporting rod.

Design of the N.R.L. Parallelism Interferometer

The design of the instrument will be considered in two parts: (I) that concerning the optical system, the principle of which has been described above in some detail, and (II) that which deals with the means for obtaining the condition that the working face of 11 will rotate in its own plane or in planes parallel to it.

(I) *Optical System*

Fig. 2 is a photograph of the parallelism interferometer, the over-all dimension from top to bottom of which is approximately 6 ft. Seen at the top of the photograph, is the mirror 4, adjustable on a brass rod which is screwed to a baseboard, attached to the wall. Vertically below the mirror is the mount 13.

This mount, a close-up view of which is shown in Fig. 3, is capable of travel up and down, and to a limited extent, around, the vertical brass tubular rod (seen at the immediate left of the mount) which is suspended by means of gimbals at its upper end. In the lower or free end of the vertical tube is inserted a steel plug, which is held by spring closure against two mutually perpendicular tangent screws in a horizontal plane. By means of these screws, final (fine) adjustment of the interference fringe spacing and configuration may be accomplished by the slight change in inclination imparted to the whole mount, and therefore to the proof-plane. The location of the screws is shown in Fig. 2.

A counterweight, encased in a vertical sheet-metal cylinder, at the extreme left of Fig. 2, is attached to one end of a phosphor-bronze wire which passes over two pulleys; the other end of the wire is fastened to the mount. By this means, the latter can be moved readily up and down and set into convenient positions on the supporting tube, no clamp being necessary.

Referring to Fig. 3, the upper end of the mount maintains closed contact with the supporting rod by means of three cylindrical rollers, equally spaced about the rod axis. The remaining constraints are obtained by means of a

pair of conical rollers at the lower end, which are held in contact with the vertical rod by gravity. Each roller, or pair of rollers is fitted on an eccentric axle to permit ready adjustment. Thus, free movement without backlash is achieved, and the effect of inequalities arising from wear, lack of straightness, etc., in the tube is eliminated.

The unit containing the elements 5 and 7 (i.e., condensing lens and diaphragm) can be seen at the top of the photograph. It is a brass tube, the lower end of which is threaded, for the purpose of adjustment, into the top plate of the mount. Behind the eye-diaphragm (near the centre of the photograph) can be seen the knurled heads of four screws used in adjusting and clamping the mirror 9.

Directly below the screws, at the bottom of the mount, can also be seen the edge of the cell containing the collimating lens 8. Beneath this again is a brass ring, in which the quartz flat 10 is supported. For the purpose of coarse adjustment (of the proof-plane with respect to the upper face of the end-gauge) this ring may be tilted by means of the arrangement shown. Here, three oversize holes in the ring receive, respectively, three brass studs which are threaded into the lower base-plate of the mount. The free, or lower, ends of the studs are also threaded for about 1 in. of their length, and on each, a nut is screwed to the limit of its run. Enclosing the threaded portion of the free end of each stud is a helical spring, one end of which is held against the nut, while the other end butts against the ring. Another nut, with which the actual adjustment is made, forces the ring against the spring.

A metal stop in the form of a ring, which can be clamped at any desired position on the vertical rod, is provided to prevent overrunning of the mount. Also provided is a series of thin Masonite covers, one of which is shown around the end-gauge in Fig. 2. These not only serve to insulate the gauge from convection currents and radiation, but also to protect it from accidents.

(II) *Turntable*

Fig. 4 is a cross-sectional drawing of the turntable of the N.R.L. parallelism interferometer. In this figure, 14 is a massive cast-iron bracket which supports the entire lower assembly and which is rigidly bolted to the concrete wall. Into the base of this casting is fitted vertically, a truncated conical steel spindle, 15, about 24 in. in length. The latter has a long fit in the base of the bracket, and is pulled firmly against a shoulder by means of a nut. At the upper and lower ends, respectively, of the vertical spindle, and fitted concentrically to it, are cylindrical bushings, 16 and 17, each with its outer face hardened, ground, and lapped. Concentric with 16 and 17, and with their mating faces lapped to fit them, is a corresponding pair of bushings, 18 and 19. These latter are fitted into a cylindrical steel pipe, 20, in the upper end of which is attached a steel plate, 21, about $\frac{1}{2}$ in. thick. This plate serves as a housing for a tempered steel stalk, 22, concentric with it and which is held against a shoulder by means of a hollow screw, 23. The lower face of this stalk, which is about $1\frac{1}{2}$ in. long, is hardened, ground, and lapped flat

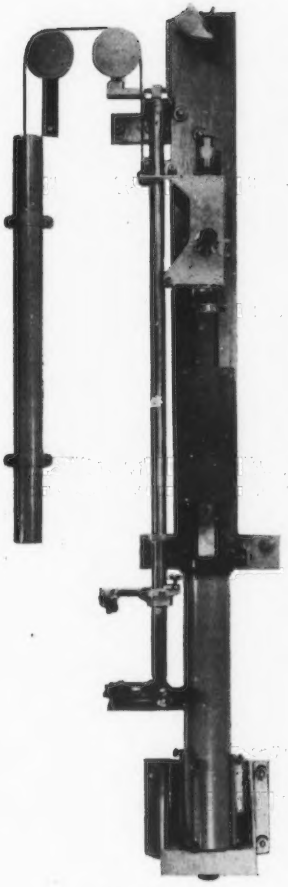

FIG. 2.

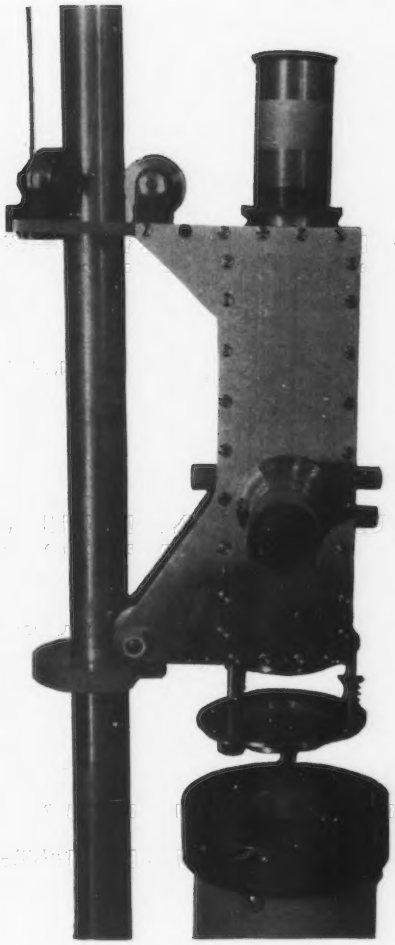

FIG. 3.

FIG. 2. *Photograph of the interferometer showing a 20 in. end-gauge in position for measurement. Below the gauge and to the left of it are the level vial and attachments used when the instrument is to be employed as a level comparator.*

FIG. 3. *Close-up view of the mount with a short end-gauge in position. The reflection of the wrung surface of the gauge can be seen in the inclined mirror beneath it.*

and perpendicular to its geometric axis. This face which is approximately 3/16 in. in diameter, rests on a hard steel ball, 24, peened into a hole in an auxiliary steel end-piece which is screwed coaxially on to the central spindle, 15. The upper end of the stalk is centrally located in a cast-iron plate, 25. In the upper face of 25 are symmetrically fitted three steel pins, 26, on which

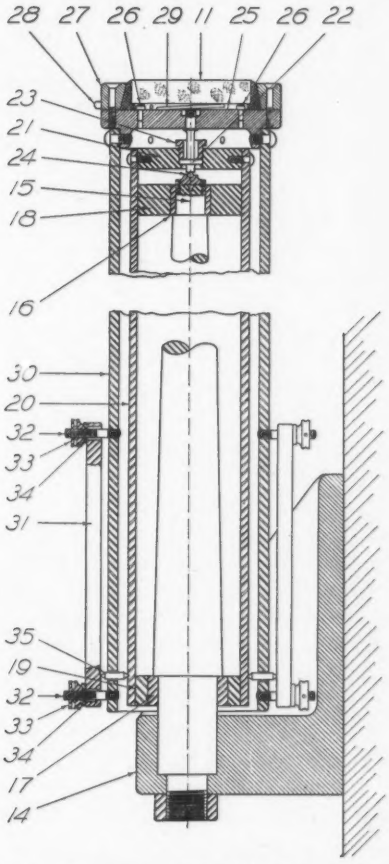

FIG. 4. *Cross-sectional drawing of the turntable.*

rests the quartz flat, 11. The flat is held in position against these pins by means of plaster of Paris, which fills the space between the cylindrical surface of the quartz flat and a cast-iron annulus, 27, attached by means of screws to 25. Leading into the space beneath the flat is a short brass tube, 28, to permit the use of an air pump for the removal of moisture. In this space is fixed a circular mirror, 29 (seen immediately below the quartz flat in Figs. 3 and 9), which is approximately 2 in. in diameter, and which has its plane inclined

about 5° to the plane of the working face of the optical flat, in order to avoid undesirable reflections. By means of this mirror, the interference pattern formed during the process of wringing can be examined, and the completeness of the wringing controlled, depending, of course, on the surface finish of the gauge. The plate 25 also serves as a support for a cylindrical steel pipe, 30, into the upper end of which it is fitted and located by means of screws. This pipe, approximately coaxial with the central spindle 15, is about 22 in. long and 4 in. outside diameter.

The purpose of the outer pipe, in conjunction with a system of four diametrically opposing levers, 31, is to provide the necessary means for the adjustment of the working face of the quartz base-plane into perpendicularity with the mechanical axis of 15. The levers 31 are of cold rolled steel about 7 in. long, and are located on studs, 32, tapped into 30. The studs themselves are threaded to receive nuts, 33, with capstan heads. The nuts are spherically seated into mating steel washers, 34. Contact between the levers and the inner pipe 20 is maintained by four pointed struts, 35, which pass through oversize holes in the outer pipe, and are seated in conical depressions in the levers and inner pipe, respectively. The vertical distance between the struts and the lower screws 32, is about $\frac{1}{2}$ in. Hence for coarse adjustment, the lower nuts impart an approximate one-to-one motion to the lower end of the outer pipe, while the stalk 22 is strained from its original position. For fine adjustment, the upper nuts impart only about 1/12 of their axial movement to the lower end of the outer pipe.

When the instrument has been put into proper adjustment, the upper or working face of the quartz flat remains accurately perpendicular to the mechanical axis of the supporting spindle, as observed from the configuration of the interference pattern when the outer assembly is rotated. Although no particular care was taken to locate the steel ball 24 concentric with the axis of rotation of the stalk (and hence of the outer assembly), the rise and fall of the working face of the quartz flat is not greater than 2×10^{-5} in. about a mean plane, or a shift of two interference bands, for a complete turn of the outer pipe. This, of course, does not impair the accuracy of the instrument, as the measured parallelism is in no way affected.

Interpretation of Interference Patterns

A simple case, involving an end-gauge in which the short edges of the rectangular gauging faces are parallel to each other, will be considered.

(I) *Short Edge of the Upper Face of the End-gauge Initially Parallel to the Proof-plane*

Fig. 5 (*a*) is a schematic diagram showing an end-gauge wrung on to the working surface of the quartz flat 11. Above the gauge is shown the inclined optical flat 10. XY represents the long edge of the gauge's upper face, which is considered to be flat. In the position indicated, 10 has been so adjusted that the line of intersection of the plane of its lower surface (proof-plane) and

the plane of the upper face of the end-gauge is parallel to the adjacent short edge of the gauge. When viewed through the eyepiece of the instrument, in monochromatic light (in this case, mercury green), the resulting interference pattern would appear as a series of equispaced parallel bands with the order of interference increasing from left to right, Fig. 5 (*b*). The direction of

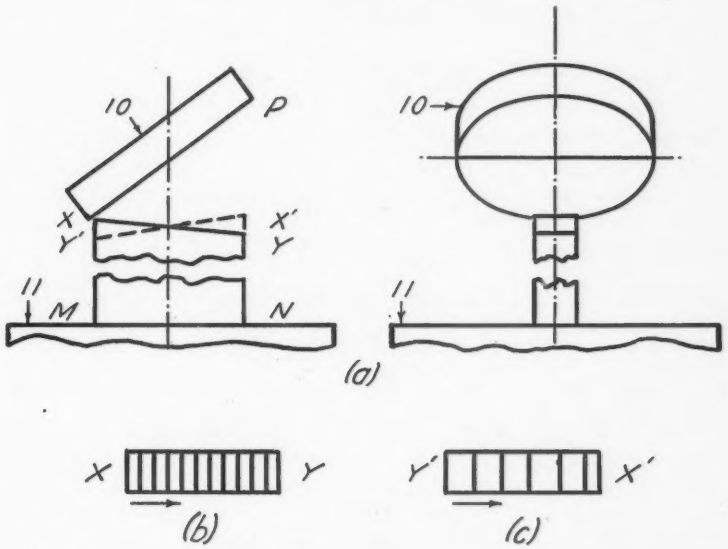

FIG. 5. *(a) Diagram showing a slightly wedge-shaped end-gauge with the short edge of the gauging face initially parallel to the proof-plane. (b) The interference fringe system associated with the gauge in this position. (c) The fringe system associated with the gauge after rotation through 180°.*

the order is easily determined by moving the appropriate tangent screw at the bottom of the supporting rod. It should be pointed out that the semi-reflecting mirror 9 turns the image upside down, but does not reverse it from left to right.

From the theory, the angle PXY contained by the two planes concerned, is:

$$n_1 \lambda/2D \text{ radian} \qquad (1)$$

where n_1 is the number of interference bands (in this case 11.0) observed along the long dimension, D, of the working face of the end-gauge, and λ is the wave-length of the incident beam of monochromatic light (5460×10^{-7} mm. approximately, for mercury green light).

If now, the lower assembly on to which the end-gauge is wrung be rotated through 180°, the long edge will take up the position of the dotted line $X'Y'$, with the resulting interference pattern appearing as in Fig. 5 (*c*). In the

same manner as above, the angle of inclination $PY'X'$ of the two planes concerned is:

$$n_2 \lambda/2D \text{ radian} \tag{2}$$

where n_2 is the observed number (in this case, 5.4) of interference bands.

If, after this rotation, the order of interference increase from left to right, the angle contained by the planes of the upper and lower working faces of the end-gauge is given by half the *difference* of the two above expressions, i.e., by:

$$(n_1 - n_2) \lambda/4D \text{ radian.} \tag{3}$$

Hence the side MX of the gauge is longer than the side NY by 3.0×10^{-5} in.

If, on the other hand, the order of interference after rotation, reverse, i.e., increase from right to left, the upper face of the end-gauge must have rotated in a vertical plane, through an angle greater than PXY. In this case, the contained angle between the upper and lower gauging faces would be given by half the *sum* of the two expressions, i.e., by:

$$(n_1 + n_2) \lambda/4D \text{ radian} \tag{4}$$

and the side MX would be longer than the side NY by 8.8×10^{-5} in. When the quantity $(n_1 \pm n_2)$ is small, as it generally is, the accuracy of the test is not impaired if $\lambda/2$ be taken as 0.00001 in.

Figs. 6 (*a*) and 6 (*b*) illustrate the first condition described. They are actual photographs taken with the camera placed outside the peep hole of the instrument. In Fig. 6 (*a*), approximately 25 interference bands can be counted, while in Fig. 6 (*b*) there are about 22. Considering the order of interference to be increasing from left to right in both cases, Equation (3) applies, and it follows that as viewed in Fig. 6 (*a*), the left-hand side of the gauge is longer than the right by

$$(25 - 22) \lambda/4 = 1.5 \times 10^{-5} \text{ in. (approximately).}$$

The transverse line, shown in the photographs, is a reference line ruled in ink on the working face of the upper quartz flat.

(II) *Upper Face of the End-Gauge Initially Parallel to the Proof-plane*

The same result (again supposing that the gauge is out of parallel along the long dimension alone) as described in the first part of (I) may be obtained by operating the tangent screws at the bottom of the vertical rod to make the proof-plane initially parallel to the upper face of the end-gauge, as shown in Fig. 7 (*a*), and then, in the same manner as before, rotating the gauge through 180°. When the long edge, XY, is parallel to the proof-plane, no fringes will be observed on the face of the gauge (if the face be perfectly flat) when viewed in the instrument. When this edge is in the second position $X'Y'$, the resulting interference pattern would appear as in Fig. 7 (*b*), in which 5.6 bands are shown, with the order of interference increasing from left to right. From the argument in (I), it follows that the side MX is longer than the side NY by $5.6\lambda/4$ or nearly 3.0×10^{-5} in.

Owing to the fact that the working face of an end-gauge is never perfectly flat, the condition in which no interference bands appear can never actually be realized. Consequently, since the flat may be tilted slightly about a mean plane, and still apparently fulfil the condition of parallelism, the second method is not considered to be as sensitive as the first.

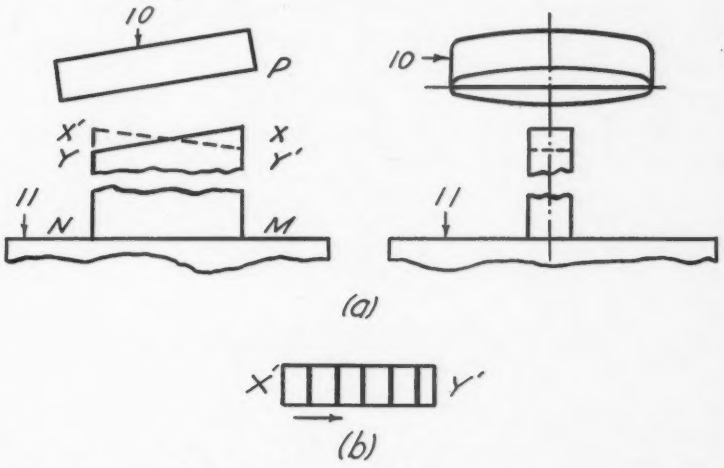

FIG. 7. *(a) Diagram showing a wedge-shaped end-gauge with its upper gauging face initially parallel to the proof-plane. (b) The interference fringe system associated with the gauge, after rotation through 180°.*

(III) *Long Edge of the Upper Face of the End-gauge Initially Parallel to the Proof-plane*

A third case, in which the same results as in (I) and (II) above are found, may be obtained with another arrangement, indicated in Fig. 8. Fig. 8 (*a*) shows two elevation diagrams of the end-gauge with the proof-plane so inclined that it is parallel to the long edge but not to the short edge of the upper face of the gauge. The resulting interference fringe system would appear as in Fig. 8 (*b*), with the bands parallel to the long edge and with the order of interference increasing from left to right as shown by the arrow.

It can be seen that after rotation, the proof-plane will no longer be parallel to either edge of the gauge's upper surface; the interference system would then appear as in Fig. 8 (*c*). Here, inversion of the image by the semi-reflecting mirror is not considered. The direction of the increasing order of interference is shown by the arrows, and the number of bands intersecting the long edge is 5.6, while the number along the short edge is still the same as in Fig. 8 (*b*), since the angle contained by the proof-plane and this edge is unaltered. Hence, as before, the side MX is longer than the side NY by 3.0×10^{-5} in.

In general, the planes containing the two gauging faces of an end-gauge intersect in a line that is inclined to both edges of the faces. Therefore, the usual practice in determining the parallelism error is to follow the procedure outlined in (III), in which the long edge of the upper face is first made parallel to the proof-plane. The direction of the increasing order of interference is then noted, and the turntable rotated. The resulting interference bands will be skewed, more or less as in Fig. 8 (*c*), but not necessarily at the original angle or with the original spacing.

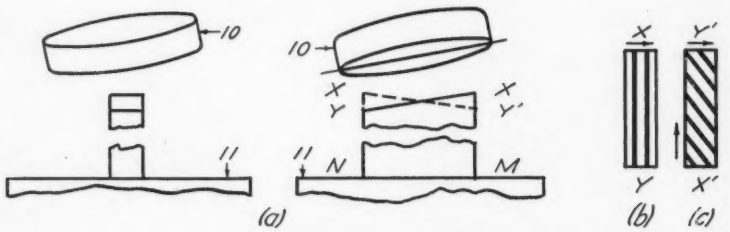

FIG. 8. *(a) Diagram showing the end-gauge with the long edge of the gauging face initially parallel to the proof-plane. (b) The interference fringe system associated with the gauge in this position. (c) The fringe system associated with the gauge after rotation.*

The interpretation now involves a combination of (I) in order to determine the parallelism error across the face (the same reasoning applies for either edge parallel to the proof-plane) and (III) to ascertain the error along the length of the face. In the case of the short dimension, i.e., parallelism error across the width, the number of bands intersecting the short edge and the direction of increasing order of interference are noted, and the parallelism error computed as in (I). In the case of the long dimension, the number of bands intersecting the long edge, and the direction of increasing order (taking into account the inversion of the direction of the order due to the mirror) are noted, and the error calculated as in (III).

Applications

The parallelism interferometer is not only useful as an instrument for assessing the parallelism error of end-gauges, particularly long ones, but it also has other uses. With it, the departure from flatness of an optically flat surface can be determined, and to a great extent the quality of the surface finish. It has also been employed as a vertical comparator in two ways:

(1) As an interferometer comparator, i.e., by the examination of the interference pattern formed in white and/or monochromatic light, between the proof-plane and the upper working surfaces of two adjacent end-gauges wrung to the quartz base plane.

(2) As a level comparator. This is described in some detail in the Appendix.

It is interesting to record that the parallelism interferometer was an indirect means of determining the absolute length of a 4 in. end-gauge of the Johansson

type in a rather unique way. The gauge in question had been sent to the Metrology Section for the precise measurement of its length and for the assessment of parallelism and flatness errors. Photographs of the Haidinger fringes, obtained when the gauge was wrung to semi-aluminiumized quartz plates to form a Fabry and Perot étalon, were taken with krypton and cadmium as the light sources. First, an exposure was made by means of a Hilger spectrograph, with the étalon in such a position that the centre of the interference ring system was to one side of the gauge, about $\frac{5}{8}$ in. from its axis; then the étalon was moved parallel to itself until the ring centre was at the same distance on the other side of the gauge. The optical distance between the plates, in each position, was found by first measuring the diameters of the rings for each wave-length to determine the fractional order of interference, and then employing the 'method of coincidences'. The mean of the two lengths obtained, corrected for phase changes at reflection, gave the average mechanical length of the gauge plus two wringing film thicknesses, while the difference of the lengths was a measure of the parallelism error across the short face dimension.

The spectrograph plates yielded usable ring diameters in three adjacent colours, red to green, but because these wave-lengths were so close together the residuals of two distinct interference orders fitted each length equally well. This gave, in all, four possible independent lengths and consequently four parallelism errors.

The parallelism error of the end-gauge was thereupon measured by means of the parallelism interferometer. The value obtained gave the clue as to which two lengths should be utilized in the actual length determination. Subsequent independent checks of the length of the gauge revealed that the value indicated by the parallelism interferometer was the proper one.

APPENDIX

A Precision Level Comparator

A sensitive level vial is an excellent means for determining small differences in the lengths of end-gauges. Thus, if a level vial be substituted for the mount on the vertical supporting rod of the parallelism interferometer, the instrument may be used as a level comparator.

Description

A close-up view of the instrument is shown in the photograph, Fig. 9, while in Fig. 2, the level vial, swung out of its working position, is seen near the lower end of the tubular rod.

In the level comparator, the level vial is supported in an unstrained position in a cylindrical brass fitting, which is cut away, as shown in Fig. 9, for the purpose of viewing the bubble and graduations. Soldered to the bottom of

the fitting is a rectangular brass block, into the lower face of which are peened two 0.125 in. hard steel balls, ½ inch apart and in line with the axis of the vial. The block is relieved by horizontal saw-cuts, and for adjustment purposes two fine-pitched screws are provided for straining the lower face in such a manner that the line of centres of the two balls can be made closely horizontal, when the bubble is in its central position. On to the top and at the centre of the upper surface of the fitting is soldered a smaller rectangular block, into which is inserted a hard steel pin. This pin is located between two parallel longitudinal hard steel knife-edges, acting as stops to limit the 'rolling' tendency of the level vial. The stops are fitted on to a brass block, carried on a movable arm of cold rolled steel. A saddle of thin brass sheet, which is also attached to the block, serves as a support for the level vial assembly; a portion of the saddle is cut away in order to receive the underneath block in which the balls are fitted. The movable arm is pivoted about a pin located in the side of a steel slider, which can be clamped at any desired height or position on the supporting rod of the parallelism interferometer. A screw, visible only in Fig. 2, butting against the top of the arm, serves to raise or lower the level assembly off or on the upper faces of the gauges being compared.

With the instrument are provided two precise level vials (made by Pessler, Germany) with attendant fittings and accessories. One of these vials has a sensitivity of 5 sec. of arc per division, while the other has a sensitivity of 15 sec. With the former it is possible to detect height differences to a precision of 0.000001 in. over a range of 0.0001 in., and with the latter, to about 0.000003 in. over a range of slightly more than 0.0002 in.

Operation

The method of operation is simple. The two end-gauges to be compared are wrung side by side, about 1/16 in. apart, on the quartz base-plate of the interferometer, and allowed to come to the same temperature. The slider is then clamped at a suitable position on the vertical rod, and the vial slowly lowered by means of the screw until the two balls rest on the respective faces of the gauges, and the cylindrical fitting is free of the saddle. Just before contact, the turntable should be rotated into such a position that the line of centres of the balls is approximately parallel to the short edges of the gauges. After allowing the vial to rest on the gauges for a time, both ends of the bubble are read. The balls are then lifted clear, the turntable rotated through 180°, and a second observation made. The bubble movement in conjunction with the calibration factor yields the difference in height of the two gauges.

Acknowledgments

The turntable assembly of the interferometer was designed by Mr. R. H. Field, Head of the Metrology Section, who also guided the design of the instrument as a whole. This unit, together with the level vial assembly, was constructed by Mr. A. A. Barks and his co-workers of the Supplementary

(a) (b)

FIG. 6. *Untouched photographs of interference fringes formed in the interferometer. (a) and (b) correspond to (b) and (c), respectively, of Fig. 5. The beat effect, noticeable in the fringes and due to the non-selectivity of the filters, does not impair the practical accuracy of the measurement. The heavy line across the centre of the gauge is a reference line ruled on the lower surface of the proof flat.*

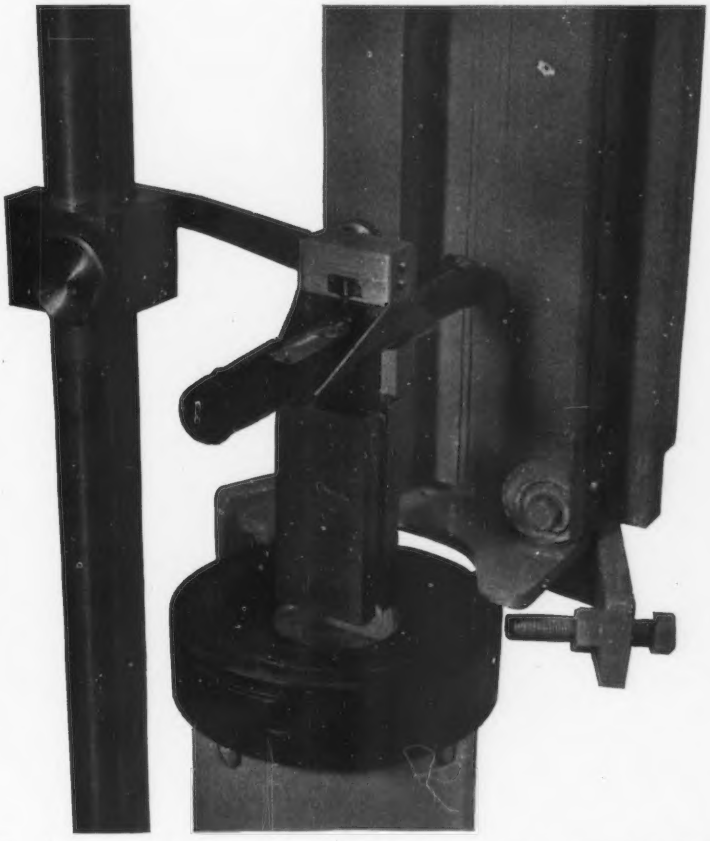

FIG. 9. *Close-up view of the level vial and attachments used to convert the parallelism interferometer into a level comparator. The mirror for determining the degree of the wringing of the gauges to the base plane can be seen below a pair of 3 in. end-gauges being compared.*

Workshop of the Physics and Electrical Engineering Division. The interferometer mount and its supports were built in the Instrument Makers Wartime Training School, Dalhousie University, Halifax, N.S. Credit is due to Mr. J. N. Cairns, of the Optics Section, who succeeded in finishing the surfaces of the quartz flats to such a high degree of precision.

Reference

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